Computer Assisted Orthopaedic Surgery

8th Annual Meeting of CAOS-International Proceedings
BRIAN L. DAVIES, PH.D.
Imperial College
Mechanical Engineering
Exhibition Road
London SW7 2BX
United Kingdom
b.davies@imperial.ac.uk

LEO JOSKOWICZ, PH.D.
Computer Assisted Surgery and
Medical Image Processing Laboratory
The Hebrew University of Jerusalem
Givat Ram
Jerusalem 91904
Israel
josko@cs.huji.ac.il

KWOK-SUI LEUNG, M.D.
Department of Orthopaedics and Traumatology
Faculty of Medicine
The Chinese University of Hong Kong
Prince of Wales Hospital
Shatin, Hong Kong SAR
China
ksleung@cuhk.edu.hk
# Table of Contents

**Introduction** ................................................................................................................................. 1  
**CAOS-International Program Committee** ...................................................................................... 2  
**Abstracts of CAOS2008 - Talks**  
  - Session I - Total Knee Replacement - Outcome Studies ............ 5  
  - Session II - Unicondylar Knee Replacement ................................. 31  
  - Session III - Technical Innovations ........................................... 39  
  - Session IV - Trauma and Osteotomy ........................................... 55  
  - Session V - THA - Leg Length Discrepancy and Coordinate Systems .............................................. 71  
  - Session VI - THA - Clinical Studies ............................................. 87  
  - Session VII - Robotics and Sensors ............................................ 105  
  - Session VIII - Revision TKR and Tool Evaluation ................. 125  
  - Session IX - Femoral Head Resurfacing ..................................... 145  
  - Session X - Spine and Tumour ................................................... 157  
  - Session XI - Anterior and Posterior Cruciate Ligament Replacement ............................................... 167  
  - Session XII - THA - Measurement Issues ................................. 183  
  - Session XIII - TKR - Patellofemoral Kinematics & Soft Tissues ......................................................... 201  
  - Session XIV - Ultrasound .......................................................... 219  
  - Session XV - Arthroscopy and Fracture Reduction .................... 229
Abstracts of CAOS\textsuperscript{2008} - Posters

ACL............................................................................................................. 243
Spine ........................................................................................................... 252
Total Hip Replacement .......................................................................... 260
Trauma & Osteotomies ......................................................................... 310
Technical Innovations & New Applications ......................................... 323
Total Knee Replacement ....................................................................... 403
Resurfacing ............................................................................................ 456
Upper Limb Fractures ............................................................................ 463

Authors Index.............................................................................................. 471
Keyword Index.............................................................................................. 479
Sponsors and Exhibitors of CAOS\textsuperscript{2008} ............................................ 484

\textit{Digital Version of this Book}

The 2008 Proceedings are available as a PDF document. If you have participated in the 8\textsuperscript{th} Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery or have purchased a copy of these Proceedings, you may download the file via:

http://www.CAOS-International.org/proceedings/2008

Username: luke
Password: swc3Po
On June 4-7, 2008 the International Society for Computer Assisted Orthopaedic Surgery (CAOS-International) will meet in Hong Kong for the 8th Annual Meeting. In past years, these conferences have established themselves as the premier scientific event in the agenda of physicians, researchers, developers, and system providers who are interested in all aspects of CAOS technology - its development as well as its clinical application and evaluation. This year, CAOS-International will have the annual scientific meeting in Asia. CAOS has been developed and is being practiced actively in many Asian countries at the present moment. Under the guidance of CAOS-International, the very active CAOS-Asia chapter has been organizing their annual scientific meetings since 2004. In 2008, CAOS-Asia will also join together with the CAOS-International annual meeting. We believe this extended meeting will be an extraordinary precious opportunity for these new technologies and research activities to be promoted and developed further in Asia. For additional information on CAOS-International as well as the past and future annual meetings, please visit the society’s homepage at http://www.CAOS-International.org/

The call for abstracts for this 8th Annual Meeting was very well received: about 180 abstracts were submitted by authors from 19 different countries. From these submissions an international Program Committee has selected 80 podium presentations and 85 posters that will be presented in Hong Kong.

We would like to take this opportunity to thank our fellow program review committee members for their efforts and time spent: Norberto Confalonieri, Florian Gebhard, Anthony Hodgson, Branislav Jaramaz, P.S. John, Leo Jokowicz, Martin Krismer, Kwok-Sui Leung, Phillipe Merloz, Lutz-Peter Nolte, Klaus Rademacher, Michael L. Swank. We are also very grateful for the support of our sponsors and all organizers, including the local teams in Hong Kong who will make this meeting possible. Special thanks go to Frank Langlotz and Karin Roth, who spent endless hours to format, edit, proof-read, and shape the manuscript of this book.

This book contains a collection of those abstracts that have been accepted as podium and poster presentations for the 8th Annual CAOS International Meeting. They have been placed in order according to their presentation sequence during the meeting. In addition, a full authors listing and a keyword index at the end of the book is available that will make it easier to find a specific abstract.

We would like to point out that the authors alone are fully responsible for the style and content of their contributions.
CAOS-International Program Committee

Brian L. Davies, Ph.D. - Chairman
Imperial College
Mechanical Engineering
Exhibition Road
London SW7 2BX
United Kingdom
b.davies@imperial.ac.uk

Norberto Confalonieri, M.D.
Orthopaedic Center (CTO)
Bignami 1
20100 Milano
Italy
norbconf@tin.it

Florian Gebhard, M.D.
University of Ulm
Department of Orthopaedic Trauma
Steinhövelstrasse 9
89070 Ulm
Germany
florian.gebhard@uniklinik-ulm.de

Antony Hodgson, Ph.D.
UBC Mechanical Engineering
6250 Applied Science Lane
Vancouver BC V6R 2L7
Canada
ahodgson@mech.ubc.ca

Branislav Jaramaz, Ph.D.
Institute for Computer Assisted
Orthopaedic Surgery
The Western Pennsylvania Hospital
4815 Liberty Avenue, Suite 242
Pittsburgh, PA 15224
USA
branko@icaos.org

P.S. John, M.D.
Medical College
Gandhi Nagar
Kottayam, Kerala 086008
India
drpsjohn@sify.com

Leo Joskowicz, Ph.D.
Computer Assisted Surgery and
Medical Image Processing Laboratory
The Hebrew University of Jerusalem
Givat Ram
Jerusalem 91904
Israel
josko@cs.huji.ac.il
Martin Krismer, M.D.
Universitätsklinik für Orthopädie
Medizinische Universität Innsbruck
Anichstrasse 35
6020 Innsbruck
Austria
martin.krismer@uki.at

Philippe Merloz, M.D.
University Department of Orthopaedic Surgery
CHU A. Michallon, BP 217
38043 Grenoble cedex 9
France
Pmerloz@chu-grenoble.fr

Lutz-Peter Nolte, Ph.D.
MEM Research Center
Institute for Surgical Technology & Biomechanics
Stauffacherstrasse 78
3014 Bern
Switzerland
Lutz.Nolte@MEMcenter.unibe.ch

Klaus Radermacher, Ph.D.
Helmholtz-Institute for Biomedical Engineering
RWTH Aachen University
Chair of Medical Engineering
Pauwelsstrasse 20
52074 Aachen
Germany
radermacher@hia.rwth-aachen.de

Michael L. Swank, M.D.
Cincinnati Orthopaedic Research Institute
9825 Kenwood Road, #200
Cincinnati OH 45208
USA
mswank2789@aol.com

Kwok-Sui Leung, M.D. - Site Chairman CAOS2008
Department of Orthopaedics and Traumatology
Faculty of Medicine
The Chinese University of Hong Kong
Prince of Wales Hospital
Shatin, Hong Kong SAR
China
ksleung@cuhk.edu.hk
Surgical Technique And Early Results After Minimally Invasive Versus Conventional Orthopilot®-Navigated Columbus® Total Knee Arthroplasty

LAMPE F, BOHLEN K

Joint Replacement Center, Klinikum Eilbek - Schoen Kliniken, Hamburg, Germany

flampe@schoen-kliniken.de

Introduction: Since the 1970s, total knee arthroplasty (TKA) has evolved as a reliable and successful procedure in the treatment of degenerative knee joint diseases. There is a discrepancy, however, between the surgeon’s definition of success, which emphasizes long-term implant performance and low revision rates, and the patient’s treatment goals, which emphasize rapid and painless return to function early in the postoperative period. The new minimally invasive approach in TKA may be the procedure that meets both patient and surgeon expectations.

There is ongoing discussion about the potential benefits of minimally invasive techniques in total joint replacement, such as less pain, faster functional recovery, less blood loss, and shorter hospitalization. There are also increased risks, such as malalignments and fixation errors, insufficient soft tissue management, and generally higher complication rates.

Navigation systems were shown to increase precision and reliability in implant alignment in conventional TKA in several studies [1-5]. In minimally invasive surgery navigation systems are supposed to help surgeons avoid errors caused by limited view of the surgical field, although there is no sufficient scientific evidence for this in the current literature yet (figure 1).

The goal of this paper is to demonstrate the detailed surgical technique of minimally invasive navigated TKA (Columbus posthesis, OrthoPilot 4.2 navigation system; B. Braun Aesculap, Tuttlingen, Germany) in video sequences and to evaluate potential risks and benefits of minimally invasive vs conventional approaches in a series of patients.
Materials and Methods: The conventional medial parapatellar (CMP) procedure carried out in 25 navigated TKAs performed at our institution was compared with the mini-midvastus split (MMS) approach used in another 25 navigated TKAs. Preoperatively, clinical range of motion (ROM), radiologic leg deformity, Knee Society Score (KSS), and Oxford Score were evaluated. Intraoperatively, leg deformity, ROM, and ligament stability were assessed using the navigation system (OrthoPilot 4.2) in the native joint and after the final prosthesis implantation in two independent navigation procedures. Range of motion and intensity of pain according to the visual analog scale (VAS) were measured during the first 10 postoperative days. On the seventh postoperative day, leg deformity was controlled radiologically. Between 3 and 6 months postoperatively, the clinical scores were re-evaluated. No statistically significant differences between the two groups were found for deformity, ROM, and clinical scores preoperatively, and no significant differences were found for deformity, ROM, and ligament stability in the native joint and after prosthesis implantation measurements by navigation intraoperatively. Postoperatively, there were no significant differences between the two groups for deformity and clinical scores. In contrast, significantly less pain according to VAS measures and quicker gain in ROM during the first 10 postoperative days were experienced in the MMS group. Complication rates were similar in both groups.

Results: According to our results, minimally invasive navigated TKA is characterized by high implant positioning accuracy, soft tissue management quality, and complication rates similar to those for CMP. Compared with the
conventional approach, minimally invasive TKA provides superior functional results and less pain in the early postoperative period. According to the literature and our results, minimally invasive TKA compared with the conventional procedure produces accurate implant positioning, soft tissue balancing, and comparable complication rates, especially if a navigation system is used to compensate for the limited view of the anatomic field. Functional results are superior, and there is less pain in the very early postoperative period (first 10 days postoperatively in our study) compared with results after the conventional approach.

**Discussion:** The clinical relevance of these findings and their impact on long and mid-term results are not yet clear. Additional research is necessary to fully evaluate potential benefits of minimally invasive TKA and the support of navigation systems to compensate for limited exposure, especially in the mid and long term.

**References**

Initial Outcome Of 100 Navigated TKA Compared To 100 Controls: An American Experience

MOK AP, JOSEPHS L, SILISKI JM

Department Of Orthopaedic Surgery, Massachusetts General Hospital, Boston, USA

siliski.john@mgh.harvard.edu

Introduction: The results of 100 PCL-retaining TKA performed by a single surgeon with computer navigation (Brain Lab, Ci/ Kolibri) were compared to a historical case-control group of 100 PCL-retaining non-navigated TKA by the same surgeon.

Materials and Methods: The surgical technique for both groups included standard surgical approach, tibia first cut, and use of the PCL-retaining PFC Sigma replacement with curved tibial insert. For the control group, the femur was prepared with an intramedullary system, and rotation was set with referencing off the posterior condyles. For the navigated group, the femoral placement was set using navigation and a gap-balancing technique. Pre- and post-operative Knee Society scores, range of motion, and alignment were documented for all cases. Operative time was documented for all cases. Lateral retinacular releases, transfusions, and hospital length of stay were also documented for all cases.

Results: In the control group pre-operatively, the mean extension was 4.9° (range 0-15°), the mean flexion was 114.3° (range 80-130°), the mean range of motion (ROM) was 109.4° (range 75-130°), the mean anatomical alignment was 0.1° valgus (range 11° varus to 20° valgus), and the mean Knee Society score was 34 (range 14-93).

In the navigated group pre-operatively, the mean extension was 6.8° (range -11-15°), the mean flexion was 110.1° (range 85-130°), the mean ROM was 103.2° (range 70-127°), the mean anatomic alignment was 0.7° valgus (range 11° varus to 14° valgus), and the mean Knee Society score was 30.3 (range 0-57).
In the navigated group, the final intraoperative mechanical alignment in extension was 0.8° varus (range 3.2° varus to 2.9° valgus).

Intraoperatively, the mean operative time in the control group was 89 minutes (range 54-123 minutes) compared to the navigated group with 99.5 minutes (range 69-130 minutes). The operative time decreased during the period of data collection, and the final 25 navigated cases averaged 89 minutes. The lateral retinacular release rate for the control group was 9% and for the navigated group 9%.

The mean hospital length of stay for the control group was 4.1 days (SD 1.5, range 2-12 days) and for the navigated group 4.2 days (SD 1.4, range 2-10 days). The mean transfusion rate for the control group was 0.3 units per patient (SD 0.8, range 0-4 units per patient) and for the navigated group 0.6 units per patient (SD 1.0, range 0-4 units per patient). In the control group, there were 4 major post-operative complications: a readmission for pulmonary embolus, a readmission for C. difficile colitis, a readmission for anemia, and a readmission for diarrhea and dehydration (C. difficile negative). In the navigated group, there were 5 major complications: 3 patients with asymptomatic DVT detected by ultrasound, a readmission for ischemic colon with perforated viscus, and an antral bleed secondary to anti-platelet therapy requiring 4 units of blood transfusion. There were no pin tract infections in the navigated group. There were no deep infections in either group.

In the control group post-operatively, at 1 year, the mean extension was 1° (SD 1.8°, range 0-5°), the mean flexion was 112.3° (SD 10.9°, range 67-130°), the mean range of motion (ROM) was 111.3° (SD 11.4°, range 67-130°), the mean anatomical alignment was 7° valgus (SD 0.6°, range 2° valgus - 10° valgus), and the mean Knee Society score was 88.7 (SD 13.8, range 47-100).

In the navigated group postoperatively, at 1 year, the mean extension was 1.7° (SD 2.4°, range 0-8°), the mean flexion was 110.7° (SD 12.1°, range 85-130), the mean ROM was 109.1° (SD 12.4°, range 85-130°), the mean anatomical alignment was 7° valgus (SD 0°), and the mean Knee Society score was 90.7 (SD 14, range 52-100).

Discussion: Computer navigation is a useful tool for TKA. It is associated with a learning curve that initially adds surgical time, but once that learning curve is passed, the surgical time is not significantly different from surgery without navigation. Peri-operative measures such as LOS, transfusion rate, major
complications and deep infections appear to show no differences between the two groups. Short-term results of navigated TKAs compared to non-navigated TKAs show no significant differences in extension, flexion, range of motion, or knee scores. This study confirms previous reports showing less variability in coronal plane alignment. Mid- and long-term follow-up will be needed to assess any differences in implant survival.
Computer-Assisted Versus Manual TKA: A Long-Term Follow-Up Of Clinical And Functional Outcomes

STULBERG SD, YAFFE MA, GALL SIMS SE

Northwestern University, Feinberg School of Medicine, Chicago, IL, USA

myaffe@md.northwestern.edu

Introduction: Computer-assisted TKA offers the potential to improve overall implant and limb alignment and reduce alignment outliers. These potential improvements in alignment, if indeed they do exist, do not translate to improvements in short-term clinical and functional outcomes. In order to determine the extent to which computer-assisted techniques influence outcomes such as pain, range of motion, knee stability, and measures of function, a long-term evaluation of these parameters is necessary. The purpose of this study was to compare the long-term clinical and patient-perceived functional results of TKA using either CAS techniques or manual instrumentation at a three-year post-operative period. No studies have thus far established whether computer-assisted TKA can offer superior long-term outcomes with regard to objective or perceived measures of clinical and functional outcomes.

Materials and Methods: 78 consecutive TKA were performed by a surgeon with extensive prior experience in both manual and CAS TKA. Of the 78 TKA, 40 were performed with manual instruments and 38 with CAS. The groups were identical with regard to age, sex, BMI, diagnosis, surgical technique, implants, and peri-operative management. Pre- and post-operative clinical examinations at four weeks, six months, one year, and three years were performed by a physician blinded to the surgical techniques. Pre-operative, short, and long-term post-operative radiographs were evaluated by an observer blinded to the surgical technique. The Knee score, which is a composite from measures of range of motion, pain, and knee stability and the Functional score, which is an assessment of patient mobility and movement independence, was evaluated according to the Knee Society scoring system.
Results: Radiographic alignment results for the anterior-posterior mechanical axis and sagittal tibial and femoral axes were similar for CAS and manual patients. Clinical results were superior for CAS patients at one-month post-operative. By six months, the gap between CAS and manual clinical results had narrowed significantly, reflecting nearly identical levels of pain but a slightly greater range of motion in favor of CAS patients. Functional results were most notable for superior CAS results at six months, reflecting greater improvements in patient mobility and function. By three years, clinical and functional measures exhibited no significant differences between CAS and manual techniques in any of the measures of interest. Major complications were not significantly different in long-term follow-up.

Discussion: CAS and manual techniques exhibited no significant clinical or functional outcome differences at short or long-term follow-up. This reflects the absence of significant post-operative alignment differences, an accurate and reproducible balance of soft-tissues at the end of the procedure, and long-term training affects afforded through the extensive use of an intra-operative navigation system. Although plain radiographs may not be sensitive enough to detect small difference in alignment outcomes between CAS and manual techniques, previous studies that have utilized computer-tomography support the findings in this study by noting no significant improvements in average alignment, clinical, or functional outcomes in short-term follow-up. A long-term benefit of CAS may be its ability to reduce alignment outliers, which has been supported in several previous studies. Reducing alignment outliers may improve the lifespan and durability of the implant, reduce the incidence of premature failure, and need for future revision.

References
A Five Year Experience With Orthopilot Navigated Columbus Total Knee Replacement

Hakki S

Department Of Orthopedics, Baypines Health Care, Florida, USA

samhakki@gmail.com

Introduction: Columbus knee represent a fixed-bearing total knee arthroplasty. Femoral component designed to stabilize the native patella has a higher curvature that when added to the posterior 3º inclination of polyethylene provide a high flexion and a stabilized knee in flexion preventing posterior dislocation of the knee. We present the results of a retrospective, intermediate-term clinical follow-up study of patella and cruciate ligament sparing navigated total knee Columbus design.

Materials and Methods: Between February 2003 and January 2008, 200 primary knee replacements were performed in 182 patients. All patellae were non-resurfaced and cruciate was retained. The average age of the patients at the time of the index procedure was sixty-seven years. The study group included 16 women and 184 men. Patients were evaluated at three months, six months, and at a 2 yearly thereafter with use of the KSS scoring with emphasis on patella symptoms and an OrthoPilot computer deflection testing of collateral ligament. Any fixed flexion deformity was noted. In addition, a radiographic analysis of the tibial, femoral, and patellar components was performed the final visit. 189 were eligible for data analysis.

Results: There was no revision of knee components. Two had manipulation for arthrofibrosis. One had early deep knee infection of gram positive cocci that was successfully treated with arthroscopic debridement and intravenous antibiotics for 6 weeks followed by 6 weeks oral antibiotics. The total clinical scores improved significantly compared with the preoperative scores for the first twelve months postoperatively and then plateaued. One hundred and eighty nine knees had adequate radiographic follow-up (average 2 years; range 1-5 years). Zonal radiographic analysis revealed 12 instances of radiolucent
lines (12 of which measured <1 mm in width), with the greatest number of radiolucent lines (10) being located around the medial tibial tray stem. None of these lines were deemed to be progressive, and no knee with a radiolucent line that measured >2 mm was revised because of failure or symptoms. Two superficial infections that were successfully treated with outpatient antibiotics for 6 weeks and was considered as a stitch abscess. The postoperative alignment was a mean mechanical axis of 0° (±0.11°) in comparison to a pre-operative mean of 5.8° varus (range 1°-18°) and a pre-operative mean of 4.4° valgus (range -1° to -13°). Knee stability revealed a mean medial/lateral (m/l) deflection in extension of 1.43° in either direction (range 0-4° in both varus and valgus directions) off zero mechanical axes immediately after surgery. The two yearly computer deflection testing revealed a mean m/l deflection of 1.49°, reflecting continuous stability with no sign of long term varus/valgus instability. The intra-operative mean knee extension was -3.8° in hyperextension, however, at 2 yearly it was significantly less measuring at a mean of 2.1° flexion. Perhaps cruciate retaining knee replacement should allow more hyper-extension intraoperatively. The mean post operative range of motion was -3.8° extension to 127° of flexion in comparison to a pre-operative mean extension of + 4° (range -14° to +20°) to 122° flexion (range 100 - 130°). (Graph-1)

Postoperatively, 72% of subjects (136) had 0-4° of native patella tilting. The other 28% (53) had postoperative patella tilting 5° - 17° (Fig.1). 11% of patellae (21 subjects) were displaced laterally (≤3 millimeters), with no associated symptoms. None had patellar displacement ≥ 3mm. (3.5%) had patella pain when asked directly about stair climbing and getting out of chair. None warranted revision.

Discussion: This first-generation cruciate ligament-retaining knee replacement was associated with a good survival rate and demonstrated clinical efficacy during the first five year follow-up interval.
Using Gait Analysis To Compare Functional Outcome Measures Following Total Knee Replacement Performed With Navigation Or Standard Instrumentation Techniques

Dillon JM, Clarke JV, Nicol AC, Picard F, Gregori A, Kinninmonth A

1 Department Of Orthopaedics, Golden Jubilee National Hospital, Clydebank, UK
2 Bioengineering Unit, University Of Strathclyde, Glasgow, UK
3 Department Of Orthopaedics, Hairmyres Hospital, East Kilbride, UK

jdillon77@hotmail.com

Introduction: The success of Total Knee Replacement (TKR) can be measured by patient satisfaction, implant longevity and functional outcome. Recent fluoroscopic studies performed following TKR have reported varying kinematics in patients with the same implant design and also different wear patterns in retrieved tibial polyethylene inserts of the same or a similar design. This suggests that surgical technique may play a major role in postoperative, kinematic function and implant longevity. TKR using computer assisted navigation has been shown to achieve more reliably accurate component positioning and alignment. Navigation also allows the surgeon to analyze intraoperative passive kinematics as the knee is moved from extension to flexion, which is useful in soft tissue management. It is hypothesized that correct prosthetic alignment and appropriate soft tissue balancing using navigation may lead to an improved functional outcome and implant longevity. This study used gait analysis to compare dynamic knee function in navigated and standard instrumentation TKA patients performing a range of everyday activities. There have been a number of recent gait analysis studies studying knee function, but there seems to be diverse methodology and a lack of consistency in results. There have been, however, selected functional outcome measures which are predictable in normal subjects knees, e.g. the presence of a biphasic moment pattern has been shown to present in all normal subjects, whereas after
TKR, subjects have demonstrated greater double-support stance times. Mean maximum flexion angle has been shown to be important in achieving certain functional activities, such as getting out of a chair, and stair climbing, and has been shown to be less after TKR than for the normal knee. The magnitude of mean adduction moment has also been associated with varus/valgus alignment (high adduction moment representing varus malalignment). We studied these outcome measures in normal subjects, and then compared the navigated and standard instrumentation TKR to the normals.

Materials and Methods: A prospective, controlled trial evaluated functional outcome using gait analysis with 20 patients in the standard group, 20 in the navigated group and 14 control subjects. Control group subjects had no history of knee pathology, knee surgery or gait abnormality. The same implant (Scorpio) and navigation system (Strykervision) was used for each patient. Using an 8-camera Vicon motion analysis system set at 120Hz (real-time motion), the following functional activities were assessed: walking, rising from/sitting in chair, ascending/descending stairs. Functional outcome measures included mean maximum flexion angle, presence of a biphasic moment pattern, double-support stance time and mean adduction moment. The average of three trials was taken for each subject. Gait analysis was performed at an average of 8 months post-op (6 to 14 months). Demographics: mean age (standard 66.3 years, navigated 67.2 years), BMI (standard 30.8, navigated 31.3), M/F (standard 9/11, navigated 8/12). Figure 1. Subject performing a level walking trial (1a), sitting (1b) and stair ascent (1c)

Results: Mean maximum flexion angle was compared for the standard group to controls and for the navigated group to controls during gait (swing phase), chair rising/sitting, stairs ascent and stairs descent (See Table 1). ANOVA was performed, with significance set at p<0.05. During gait, double-stance support time was greater in the standard group (mean 17% gait cycle) than for the navigated group (mean 15.5% gait cycle). Biphasic moment pattern was detected in 9/20 (45%) standard, 16/20(80%) navigated; adduction moment was 0.4Nm/kg (normal), 0.34 (navigated, p=0.34) and 0.30 (standard, p<0.05). Maximum flexion angle was greater for the navigated group than the standard group in gait (72.6° and 65.6°), chair sitting/rising (92.8° and 82.5°), stair ascent (99° and 82°) and stair descent (103° and 86°). P < 0.05 for all activities. The mean maximum flexion angle for both navigated and standard TKR was less than for the control group during level gait, chair rising/sitting and stair ascent/descent. However, the navigated group achieved a greater mean maximum flexion angle than the standard group, which was similar to the control group.
when performing a variety of normal daily activities. In particular, there was no significant difference in mean maximum flexion between navigated and control groups for level walking, and chair rising/sitting. A biphasic moment pattern was detected in 80% (16/20) of navigated subjects (compared to 45% or 9/20 of standard), and mean double stance support time was greater in the standard group. These kinetic patterns show similarities between the controls and the navigated group. Hilding showed that TKR’s considered ‘unstable’ by RSA, had increased maximum adduction moments during gait. In this study, the mean adduction moment was lower in the navigated group, which suggests more accurate sagittal alignment, as would be consistent with previous alignment studies. Overall, navigation achieved an improvement in predictable dynamic functional knee outcomes compared to those where a standard instrumentation method was used. Table 1: Comparison of mean maximum flexion angle between standard or navigated to controls

<table>
<thead>
<tr>
<th>Subject</th>
<th>Maximum knee flexion (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level walking</td>
</tr>
<tr>
<td>control</td>
<td>73.5</td>
</tr>
<tr>
<td>navigated</td>
<td>72.6 (p=0.74)</td>
</tr>
<tr>
<td>standard</td>
<td>65.6 (p=0.009)</td>
</tr>
</tbody>
</table>

Discussion: Computer navigated TKA results in an improved dynamic functional outcome compared to using a standard instrumentation method.

References

5. Hilding MB et al. JBJS 78-B(1) 1996, 66-73
The Learning Curve With Computer Assisted Total Knee Arthroplasty: A Novice Compared To An Experienced Navigator

Baines J, Deakin AH, Picard F

Department Of Orthopaedics, Golden Jubilee National Hospital, Clydebank, UK

angela.deakin@gjnh.scot.nhs.uk

Introduction: Computer assisted total knee arthroplasty (TKA) is still a relatively novel technique that has not yet established itself as routine in the UK. According to the 4th report of the National Joint Registry of England and Wales only 2% of TKAs were carried out using navigation in 2006. Surgeons wishing to adopt any new practice undergo a learning curve. The duration of the learning curve experienced with navigated TKA and its cost in terms of complications has not been well defined in the literature. This study analyses the learning curve of a newly appointed consultant who was experienced with TKA but with no previous exposure to navigated TKA by using an experienced surgeon, who has been employing this technique for over 10 years and has completed over 1000 navigated TKAs, as a baseline.

Materials and Methods: The study used the inexperienced surgeon’s first ever fifty navigated TKAs and the experienced surgeon’s most recent fifty TKAs over the same period (April-September 2007) in the same theatre using the same CT free navigation system (Orthopilot, BBraun, Aesculap) and prosthesis (Columbus, BBraun, Aesculap). The rest of the operating theatre staff were trained in computer navigation and technical support was provided by the system manufacturers. Operative time, actual tibial and femoral bone cuts and intraoperative limb alignment both before and after prosthesis implantation were recorded prospectively, along with the navigation specific difficulties and complications encountered by the inexperienced surgeon. The two patient populations were compared to see if there was bias in their initial deformities. There was no significant difference between the two surgeons patients for pre-
operative flexion deficit angle (p = 0.10). There was however a statistically significant difference between the two groups for pre-operative mechanical femorotibial angle (p = 0.026). The range for the two groups was similar (-10° to +15° for the novice and -12° to 14° for the experienced surgeon) but the distribution for the experienced surgeon had slightly less knees around 0°.

**Results:** There was no statistical difference in the accuracy of intra-operative limb alignment post prosthesis implantation in either the coronal (p = 0.33) or sagittal (p = 0.35) planes between the novice and experienced surgeon. There was no difference in the executed bone cut angles (tibial p = 0.79, femoral p = 0.92). The tibial posterior slope angle was between 0°-2° for the novice surgeon and 0°-3° for the experienced surgeon. The femoral posterior slope angle was between 0°-2° for both surgeons. The operating time showed a difference between the two surgeons with the novice having a median of 80 mins (inter-quartile range of 20 mins) and the experienced surgeon had a median of 70 mins (inter-quartile range of 20 mins), p = 0.001. However there was a statistically significant reduction in operating time between the inexperienced surgeon’s first twenty and last twenty TKAs (p = 0.001). Comparison of the last 20 TKAs for each surgeon showed no difference in the operative time (medians of 70 mins and 75 mins respectively, p = 0.945), Figure 1.

**Discussion:** The navigation specific difficulties and complications recorded for the novice navigator were all related to the trackers: one late intraoperative
tracker loosening in osteoporotic bone; one tibial tracker placed too proximally; one superficial infection in a tibial tracker wound and one incompletely engaged pin-tracker coupling which brought about the only conversion to manual TKA in this series. Most of the above complications occurred in the second half of the learning curve. The inexperienced navigator only found data acquisition a difficulty on the first valgus knee completed with a lateral parapatellar approach but this did not lead to any complications.

This study shows that with the appropriate infrastructure, previous surgeon experience of TKA, appropriately trained operating theatre staff and initial technical support from the implant/navigation system providers a surgeon new to navigation can safely and efficiently adopt this new technology in TKA. The only parameter assessed that underwent a clear learning curve was the operative time, which took approximately 20 procedures to approach the same as the experienced surgeon. We conclude that in terms of execution and outcome, a beginner using computer assisted TKA can match the results of an experienced navigator from the outset.
The Mathematical Relationship Between Valgus Deformity And Tourniquet Time In Navigated Total Knee Arthroplasty

SAMPATH SAC, VOON SH, SANGSTER M, DAVIES HG

The Bluespot Knee Clinic, The Classic Fylde Coast Hospital, Blackpool, UK

shameemsampath@hotmail.com

Introduction: Valgus knees can present significant problems during total knee arthroplasty (TKA). Dissimilar bone and soft-tissue deformities compared to Varus knees complicate restoration of proper alignment, positioning of components and attainment of joint stability [1]. Post-operative corrections gained following TKA in severe Valgus deformities are not as good as those in well aligned knees and the surgery can take considerably longer [2]. Computer assisted orthopaedic surgery was introduced to counter the problems of implant malalignment by improving the accuracy of bone cuts and soft tissue balancing. The main drawbacks were thought to be the increased operative time of 30 minutes or more [3] and the learning curve. The learning curve has been described [4] but not quantified in terms of operative time or number of cases. The aim of this study was to determine if there was a significant mathematical relationship between the severity of the pre-operative Valgus deformity and the length of operative time. We also wanted to investigate the influence of the patient’s Body Mass Index (BMI) and the surgeon’s experience.

Materials and Methods: This prospective study included all TKA patients with a Valgus deformity in our clinic over 35 months with no exclusions. A single surgeon (SACS) experienced in non-navigated TKA implanted the e.motion rotating platform TKAs (BBraun-Aesculap, Tuttingen, Germany) using the OrthoPilot® Navigation system version 4.2 with soft tissue management. The lateral parapatella approach was used with sequential soft tissue releases as indicated at the time of surgery. The pre and post-operative mechanical axes in the coronal plane were recorded by the OrthoPilot®. No patella resurfacing was done and all tibial components were cemented.
Surgery was carried out using a pneumatic tourniquet inflated to 350mmHg after the limb was draped and elevated. It was deflated immediately after the wound had been closed and covered with a sterile dressing. The tourniquet times were recorded by the tourniquet machine which was managed by the anaesthetic staff and not visible to the surgical team. The tourniquet time was considered to be the definitive time for the complete procedure and allowed us to accurately compare each operation.

Patient demographic information, including gender, weight and height were obtained pre-operatively. The BMI was calculated. The experience of the surgeon with the OrthoPilot® system was taken to be the total number of navigated e.motion knees he had implanted previous to each case.

Results were analysed using SPSS 15.0 (SPSS inc. Chicago, USA).

Results: We implanted 72 TKAs for Valgus deformities into 67 patients (51 women and 16 men) comprising 27 left and 45 right knees. 225 TKAs were done for Varus knees during this period. The results are shown in table 1.

There was a significant difference between the PreOP Valgus and PostOp Valgus (P=0.0001). Simple regression analysis demonstrated a statistically significant relationship between TT and the degree of pre-operative Valgus. Tourniquet time = 58.1 + 2.3*Pre Op Valgus (See figure 1) (p= <0.0001, R² = 39.9%). The S factor is 58.1. The BMI and the total number of previous navigated knees done by the surgeon were not statistically significantly related to the tourniquet time.

Discussion: In this series of 72 computer navigated TKAs we corrected all cases (except one) to within 3.0° of the neutral axis despite pre-operative Valgus deformities of up to 22°. In the single outlier (21° Valgus Pre Op and 7° Valgus Post Op) there was significant tension from scarring around the lateral popliteal nerve due to a previous lower femoral osteotomy and it was not considered safe to attempt further correction.

The data showed a significant relationship between TT and pre-operative Valgus deformity. We have proven that the more difficult cases, i.e. those with large pre-op deformities, take longer.

Learning curves are well recognised in surgery however we found no significant learning curve for a knee surgeon previously experienced in non-navigated TKA, when doing navigated TKA on Valgus knees. This is unlike our findings for navigated uncemented TKA in Varus knees [6] and may be due to the extra time used in the surgical approach, the soft tissue releases, and cementation.

We have termed the constant (58.1) in our formula the “S-factor” or Surgical
Factor. This may relate to the natural speed at which a surgical team works. It would be interesting to compare these findings with those of other surgical teams.

39.9% of the variation in the data is accounted for by our mathematical formula. We are not aware of another description of a quantitative method for relating TT to Pre Op Valgus in TKA. The formula has implications far wider than the procedure itself, although more work needs to be done to improve the accuracy of the mathematical model.

The mathematical relationship we have described may help surgeons plan their operating lists with a greater degree of accuracy, thereby allocating resources more effectively.

<table>
<thead>
<tr>
<th>factor</th>
<th>Mean (SD)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Operative Valgus</td>
<td>6° (5.0)</td>
<td>1°</td>
<td>22°</td>
</tr>
<tr>
<td>Post Operative Valgus</td>
<td>0.5 (1.5)</td>
<td>3° Varus</td>
<td>7°</td>
</tr>
<tr>
<td>Tourniquet Time (TT)</td>
<td>72 min (18.3)</td>
<td>41 min</td>
<td>135 min</td>
</tr>
<tr>
<td>BMI</td>
<td>27.6 kg/m² (5)</td>
<td>19 kg/m²</td>
<td>46 kg/m²</td>
</tr>
</tbody>
</table>

References

Detailed Analysis Of Operating Time In CAS And Manual TKA Interventions - Preliminary Study

BIGNOZZI S, NOFRINI L, NERI MP, LO PRESTI M, MARCACCI M

Istituti Ortopedici Rizzoli, Bologna, Italy

s.bignozzi@biomec.ior.it

Introduction: Several studies have analyzed, in the past, the benefits given by computer assisted surgery (CAS) in total knee arthroplasty (TKA). Most of those papers have been focused in the comparison of postoperative leg and implant alignment, which is the core goal of the intervention and on registering the operating times. Within the time needed for CAS techniques there is a general consensus in reporting an increased time. But there is a lot of variability in the amount of additional time and on the method used for time recording it. Several studies, starting from a clinical point of view, reported the skin to skin time, which includes some surgical steps which are in common between CAS and conventional surgeries and may bias the analysis. Other studies compared the surgical time of expert surgeons, using for CAS system for the first times, which has an intrinsic bias due to the practice of expert surgeon to the manual instrumentations. The goal of this work was to analyze in detail the time requested for the different steps of CAS TKA and compared with the conventional technique.

Materials and Methods: Two surgeons have been involved in the study. One expert surgeon on TKA, with few experience in CAS system and a young surgeon with few experience both in TKA and CAS systems. Both surgeons were asked to perform 10 interventions (5 CAS - 5 non CAS alternatively). Patients included in the study had an average age of 71 years (64-79), preoperative leg alignment ranged from 11 varus to 7 valgus. Informed consensus was obtained for all patients. In order to reduce the variability in the utilization of the manual technique, the prosthesis and the instrumentation (Gemini, Waldemar Link, Hamburg, Germany) were not utilized before by both surgeons. So was also the navigation system (BLU-IGS, Orthokey, Delaware) utilized by the two surgeons. Both surgeons and nurses were properly instructed for the two
surgical techniques by the product specialists before starting the study. During the intervention the following times were registered: skin access, tibial cut done, ligament balancing, femoral distal cut done, other femoral cuts done, trial implant removal. In this way we avoided to include in the analysis most of the patient-based time bias, such as the time needed for possible patellar resurfacing and for final implant positioning. For the young surgeons, possible cut corrections, made by the expert surgeon who was following him, were also noted. Postoperative radiographic analysis was also performed in order to assess the final outcome of the intervention.

Results: Average time requested for each step of intervention by the two surgeons are reported in figure 1. The two curves are comparable even if the CAS procedure has a bigger standard deviation. For the conventional technique corrections made by the expert surgeon for tibial cuts were 4 times, for femoral distal cut 2 times and other femoral cuts 2 times. For the CAS procedure there was no tibial cut correction, 1 correction for femoral distal cut and 2 corrections for other femoral cuts. Postoperative leg alignment was within the range of $180\pm3^\circ$ for both techniques for all patients.

Figure 1. Average time curve of conventional (10 cases) and CAS (10 cases) TKA surgeries, performed by two surgeons.

Discussion: In this study we analyzed in detail the time requested to perform the main steps of TKA surgery. The results reported on table 1 shows that during the learning curve the times requested for both techniques (CAS and conventional) are comparable, in particular the time requested for navigated array fixation and patient registration, was similar at the time requested for extra-medullary jig fixation. This result may be related to the fact that the navigation system utilized does not request surface registration for bone morphing. The time requested for the femoral distal cut, is greater in the CAS technique. The reason of this is that the CAS technique needs more time during femoral planning, which includes all femoral cuts, than the manual instrumentation, on the other hand for other
femoral cuts the time requested is lower because the planning was previously performed. An interesting data is the difference in the standard deviation of the data: the conventional technique has a very small range, related to the fact that the surgeon has more confidence with manual tools, so their learning curve is short, on the other hand the CAS instrumentation requested more time for first cases and a longer learning curve, but after 5 cases time for surgery is slightly lower than conventional technique. Data about cut corrections shows that the incidence of possible errors in young patients can be reduced by CAS technique and that some of the time of conventional technique may be used to refine the cut performed. This preliminary results of the study shows interesting results in the use of CAS and manual instrumentation. The time requested to perform the intervention is comparable. The continuation of the study will show if the learning curves of the two techniques will also be comparable or if operating times will stabilize with a different number of patients.

References


Hungerford DS. Title: No Computer-assisted surgery: still just “boy toys” for the passionate few.Counterpoint Source;Orthopedics. 2005 Sep;28(9): 941.
Navigated Revision Total Knee Replacement

JENNY JY, BOERI C, DIESSINGER Y, CIOBANU E

Orthopaedic Department, University Hospital, Strasbourg, France

jean-yves.jenny@chru-strasbourg.fr

Introduction: Revision total knee replacement (TKR) is a challenging procedure, especially because most of the standard bony and ligamentous landmarks used during primary TKR are lost due to the index implantation. However, as for primary TKR, restoration of the joint line, adequate limb axis correction and ligamentous stability are considered critical for the short- and long-term outcome of revision TKR. There is no available data about the range of tolerable leg alignment after revision TKR. However, it is logical to assume that the same range than after primary TKR might be accepted, that is ± 3° off the neutral alignment. One might also assume that the conventional instruments, which rely on visual or anatomical alignments or intra- or extra-medullary rods, are associated with significant higher variation of the leg axis correction, especially in cases with significant bone loss which prevents to control the exact location of the usual, relevant landmarks. Navigation system might address this issue.

Materials and Methods: We used an image-free system (ORTHOPILOT TM, AESCULAP, FRG) for routine implantation of primary TKR. The standard software was used for revision TKR. Registration of anatomic and cinematic data was performed with the index implant left in place. The components were then removed. New bone cuts as necessary were performed under the control of the navigation system. The size of the implants and their thickness was chosen after simulation of the residual laxities, and ligament balance was adapted to the simulation results. The system did not allow navigation for intra-medullary stem extensions and any bone filling which may have been required. This technique was used for 54 patients. The accuracy of implantation was assessed by measuring following angles on the post-operative long-leg radiographs: mechanical femoro-tibial angle (normal = 0°, varus deformation was described with a positive angle); coronal orientation of the femoral component in
comparison to the mechanical femoral axis (normal = 90°, varus deformation was described with an angle < 90°); coronal orientation of the tibial component in comparison to the mechanical tibial axis (normal = 90°, varus deformation was described with an angle < 90°); sagittal orientation of the tibial component in comparison to the proximal posterior tibial cortex (normal = 90°, flexion deformation was described with angle < 90°).

Individual analysis was performed as follows: one point was given for each fulfilled item, giving a maximal accuracy note of 4 points. Prosthesis implantation was considered as satisfactory when the accuracy note was 4 (all fulfilled items). The rate of globally satisfactory implanted prostheses and the rate of prostheses implanted within the desired range for each criterion were recorded.

**Results:** Limb alignment was restored in 88%. The coronal orientation of the femoral component was acceptable in 92% of the cases. The coronal orientation of the tibial component was acceptable in 89% of the cases. The sagittal orientation of the tibial component was acceptable in 87% of the cases. Overall, 78% of the implants were oriented satisfactorily for the four criteria.

**Discussion:** The navigation system enables reaching the implantation objectives for implant position and ligament balance in the large majority of cases, with a rate similar to that obtained for primary TKA. The navigation system is a useful aid for these often difficult operations, where the visual information is often misleading. The navigation system used enables facilitated revision TKA.
Navigated Shorter Incision Or Smaller Implant In Knee Arthritis?

CONFALONIERI N, MANZOTTI A, MOTAVALLI K, MONTIRONI F

1st Orthop Dept, Cto Hospital, Milan, Italy

alf.manzotti@libero.it

Introduction: The authors performed a matched paired study between 2 groups UKR or CA-TKR implanted with a mini-incision (MICA group) in the treatment of isolated medial compartment knee arthritis. The Authors hypothesized that UKR offers a real less invasive surgery with lower economical costs despite a worse limb/implant alignment. Furthermore at a minimum 40 months follow-up they hypothesized that this small implant guarantees still both better clinical score and patient satisfaction than in the MICA group.

Materials and Methods: Thirtytwo patients with isolated medial compartment knee arthritis who underwent to a medial UKR from February 2001 to September 2002 were included in the study (UKR group). In all 32 knees the arthritic change was graded according to the classification of Ålback 1. Arthritic change did not exceed grade IV in the medial compartment and grade II in the patello-femoral compartment. All patients had an asymptomatic patello-femoral joint. All patients had a varus deformity lower than 8° and a body mass index lower than 30. No patient had any clinical evidence of ACL laxity or flexion deformity and all had a preoperative range of motion of a least 110°. At a minimum follow-up of 48 months, every single patients in group A was matched with a patient who had undergone a computer assisted TKR performed with a less invasive approach (shorter than 12 cm) for an isolated medial compartment knee arthritis between August 1999 and September 2002 (MICA group) in our hospital. At latest follow-up the clinical outcome was evaluated using both the Knee Society Score and a dedicated UKR score developed by the Italian Orthopaedic UKR Users Group (GIUM). The HKA angle and the Frontal Tibial Component angle (FTC) were measured at latest follow up on long leg standing anterior-posterior radiographs and the mean values between the 2 surgeons assessments were used as final values. Furthermore during the hospital staying we registered in both the groups when each patients was
standing comfortably in full weight-bearing according to a self-answered questionnaire and the data were compared. Statistical analysis of the results was performed using parametric test (Student’s t-test). A statistical comparison of the percentage of results for the GIUM score was performed using the Chi-square test. A statistically significant result was given a $p \leq 0.05$.

**Results:** Both hospital stay and operative time were statistically longer obviously in MICA group. In the UKR group the mean surgical time was 51.5 minutes (range: 36-75) ($p<0.001$) while in the MICA group was 108.8 minutes (range: 80-132) ($p<0.001$). In the UKR group the patients remained in the hospital for a mean of 5.1 days (range: 3-7) and in the MICA group 8.2 days (range: 4-16). At the latest follow-up the mean Knee Society Score was 80.5 (range: 70-100) and 78.4 (range: 70-87) for group A and B respectively. No statistically significant difference was seen for the Knee Society score between the 2 groups ($p=0.08$). The mean Functional score was 83.5 (range: 73-100) for group A and 78.8 (range: 59-90) for group B. A statistically significant difference was seen for the Functional score with superior results for group A ($p=0.02$). A statistically significant difference was seen for the GIUM score with better results for group A ($p=0.01$). The mean GIUM score was 76 (range: 67-90) and 73.02 (mean: 65-85) for group A and B respectively. At latest follow up the mean HKA angle was 176.8° for group A (range: 174°-182°) and 179.3° for group B (range 177-182) ($p<0.001$). The mean FTC angle was 86.9° (range: 84°-90°) and 89.4° (range: 87°-92°) for group A and B respectively ($p<0.001$). All TKR implants were positioned within 4 degrees of a HKA angle of 180° and FTC angle of 90°.

**Discussion:** At the latest follow-up (minimum 48 months) no statistically significant difference was seen in the post-operative Knee Society score for either group. However, significant differences were seen between the 2 groups in the functional results and in the GIUM score with better results in the UKR group. All the patients achieved a range of motion greater than 120° and could walk for longer distances. During the hospital staying in this group the patients reported a statistically significant earlier full weight-bearing. This was despite a significant less accurate limb alignment. In addition to inferior results for the computer assisted mini-invasive TKR group the costs of the procedure were obviously greater because of the expensive implants and technology along with statistically significant longer surgical times and hospital stay.
Navigated Minimal Invasive Unicompartmental Knee Replacement

JENNY JY, Diesinger Y, Boeri C, Ciobanu E

Orthopaedic Department, University Hospital, Strasbourg, France

jean-yves.jenny@chru-strasbourg.fr

Introduction: Even if the optimal alignment after UKR remains controversial, it has been postulated that the accuracy of implantation was an important prognostic factor for the long term results after UKR. Several authors demonstrated that the accuracy of implantation of UKR was higher with the help of a navigation system in comparison to the conventional, manual technique. Minimal invasive techniques have been developed to decrease the surgical trauma related to the prosthesis implantation. However, there might be a concern about the potential of minimal invasive techniques for a loss of accuracy, probably related to the shorter joint approach. In that way, navigation might help to compensate for these difficulties.

We wanted to compare the accuracy on implantation on post-operative X-rays of two series of UKR implanted with the same navigation system and with either conventional or minimal invasive approach. We hypothesized that the use of the minimal invasive approach will decrease the accuracy of the procedure.

Materials and Methods: We conducted a prospective, controlled, observational study. Inclusion criterion in the study group was the minimal invasive, navigated implantation of a Univation® UKR (Aesculap, Tuttlingen, FRG) for primary varus gonarthrosis between October 2005 and October 2006. There were no exclusion criteria. The historical control group consisted of patients who underwent a conventional navigated implantation of a Search® UKR (Aesculap, Tuttlingen, FRG) between April 2004 and September 2005. All implantations were performed by the same experienced knee reconstruction surgeon (JYJ).

The same navigation system is used in both groups, an intra-operative non-image based one (OrthoPilot®, AESCULAP, Tuttlingen, FRG). The accuracy of implant positioning was determined using pre-discharge standard antero-posterior and lateral radiographs. Following angles were...
measured: mechanical femoro-tibial angle, coronal orientation of the femoral component in comparison to the mechanical femoral axis, sagittal orientation of the femoral component in comparison to the distal anterior femoral cortex, coronal orientation of the tibial component in comparison to the mechanical tibial axis, sagittal orientation of the tibial component in comparison to the proximal posterior tibial cortex.

Both UKR were expected to be implanted as follows: coronal mechanical femoro-tibial angle between 0 and 5° of varus, coronal orientation of the femoral component of 90°±3° (for control group) or 80°±3° (for study group), sagittal orientation of the femoral component of 90°±3°, coronal orientation of the tibial component of 90°±3°, sagittal orientation of the tibial component of 87°±3°. When the measured angle was in the expected range, one point was given. The accuracy note was defined as the sum of all points given for each patient, with a maximum of 5 points (all items fulfilled) and a minimum of 0 point (no item fulfilled).

The primary criterion was chosen to be the radiological accuracy note for the post-operative X-ray evaluation. We compared all criteria between the two groups with a Student t-test (means) and a Chi² test (percentages) at a 0.05 level of significance. Post-hoc calculation assessed that the data allowed a power of 0.20 to detect a 0.6 point decrease in the mean accuracy note in study group in comparison to control group.

Results: 120 cases were enrolled in the study: 60 in the study group and 60 in the control group. There were 42 male (35%) and 78 female (65%) patients, with a mean age of 65 ± 6 years (range, 44 to 87) at the time of surgery. Mean BMI was 29.5 ± 8.2 (range, 22 to 46). Pre-operative pain KSS was 55 ± 11 points (range, 23 to 79) and pre-operative functional KSS was 60 ± 12 points (range, 45 to 90). Pre-operative coronal mechanical axis was 7.5° ± 4.8° (range, 2° to 19°). Pre-operative Ahlback grading showed 53 grade 2 (44%), and 67 grade 3 (56%) knees. There were no significant differences in all pre-operative parameters between the two groups.

The mean accuracy note was 4.2 ± 1.2 (range, 2 to 5) in the control group and 4.1 ± 0.8 (range, 2 to 5) in the study group (p > 0.05). 36 cases (60%) of the control group and 37 cases (62%) of the study group had the maximal accuracy note of 5 points (p > 0.05).

Discussion: Minimal invasive navigated implantation of a UKR is desirable, but the main goal must remain accuracy of implantation. Our study hypothesis was rejected: we observed no significant decrease in the accuracy of a navigated implantation of an UKR with a minimal invasive approach in comparison to the conventional one. The navigation system used allowed avoiding any loss of
Unicondylar Knee Replacement

accuracy due to the minimal invasive approach to the knee joint. This study was not randomized. We considered that true randomization would probably have had a poor acceptance among patients who are currently well informed about the possible advantages of minimal invasive surgery, thus introducing significant bias.

Operating time is increased by the use of a navigation system in comparison to conventional, manual technique. A 10 minute extra-time is generally reported. The use of the minimal invasive technique did not involve an additional increase, probably because the operating workflow was only minimally modified in the study group in comparison to the control group. We consider this additional operating time as acceptable with respect to the additional information we can get by the navigation system.

Minimal invasive technique did not modify the rate and the severity of intra-operative or early post-operative complications. This technique can be considered as safe and effective.

This study was designed to document the radiological accuracy of implantation. We did not analyze the issue of possible quicker rehabilitation after minimal invasive implantation, because our rehabilitation protocol changed between the two periods of time for control or study group. A specifically designed study should be promoted in the future.

Discussion: Navigated minimal invasive technique for UKR proved to be effective. The concern about a possible loss of accuracy was actually addressed by the navigation system. More long term information must be collected. However, this technique is currently the routine way of implanting UKR at our institution.
Minimal Invasive Robot Assisted Unicompartmental Knee Arthroplasty

PEARLE A1, O’LOUGHLIN P1, LIPPINCOTT C2, KENDOFF D

1 Hospital For Special Surgery, New York, USA
2 Mako Surgical Corp., Ft. Lauderdale, Fl, USA

kendoffd@hss.edu

Introduction: Compared to the outcome of total, unicompartmental knee arthroplasties (UKA)’s do show inconsistent longevity. Revision rates of between 10% and 20% have been reported. Correct alignment of the femoral and tibial components has been shown to be most objectively quantifiable factor.

Recent technical innovations in UKA have included the use of computer-assisted navigation technology. This has been shown to improve postoperative leg alignment, however a improvement of the implant positioning itself has not been demonstrated yet. Technical developments recently include the use of robot-assisted techniques. Due to maximal invasiveness earlier robot systems for total knee and hip arthroplasties were not widely employed. There have been novel robotic systems and concepts developed to improve the clinical efficacy of this technology to UKAs. These ‘semi-active’ systems give the surgeon active control over the robot. We report our first clinical series of UKA using a completely new semi-active robotic system for the implantation of the StelKast knee. This CT-based technology in combination with a navigation module allows for a complete computer-assisted planning of the implant positioning and further robot-assisted, pre-defined burring of the tibial and femoral component cavities in vivo. We report about our first clinical series.

Materials and Methods: Based on the pre-operative CT image, the system allows for pre-operative planning of the femoral and tibial implant position, including: coronal and sagittal alignment, overall leg alignment, overlapping of the components in extension, geometric alignment of varus/valgus of femoral component in relation to the tibia implant, and finally the tibial implant positioning relative to the posterior tibial wall on the navigation screen of the robot. Consequently, the bone resection areas are defined automatically by the
system and boundaries for the cutting instrument are set to prevent cutting into areas out of the designated prosthesis geometry. The Tactile Guidance System (TGS) [MAKO Surgical Corp., Ft.Lauderdale, FL] consists of 3 components: robotic arm, optical camera and operator computer cart. The robotic arm features 5 degrees of freedom, whose movement is limited within the incision site via the 3-D virtual boundaries set in the software. The distal end of the robot is connected to a high speed burr. There is no need for a rigid fixation of the patient to the robot.

The surgeon moves the robotic arm by guiding a force controlled tip within the defined boundaries. The surgeon can sense when cutting bone and the feedback mechanism of the robot includes the active prevention of inaccurate motion out of the designated areas. The robot gives the surgeon active feedback (haptic and audio) and allows for a quick burring process of even complex shapes of the femoral and tibial bone surface. In addition, excessive pressure against the limits of the 3-D cutting volume or rapid movement of the patient’s anatomy immediately stops the cutting instrument, preventing unintentional resection outside the implant geometry from occurring.

Three burr sizes are used during surgery. A 6mm diameter spherical burr for rapid removal of the major bone material and for resection for the femoral post. A 2mm diameter spherical burr is used for the fine finishing and the corners of the cutting volume. Deep milling of the mini femoral canal is done with a 1.2mm router. The complete burring process is displayed upon a dedicated surgeon display, which also shows the 3-D model of the knee, indicating the bone material remaining to be removed. The StelKast unicondylar knee system was used in all patients. Permanent graphical feedback on the navigation screen visualises the actual achieved vs. planned cavity, specifically based on the preoperative planning. Once both complete cavities are milled out, femoral and tibia component trials are inserted and a complete flexion-extension arc is performed. Computerized simulation of the implants in situ show the actual overlapping of the implant components giving the surgeon feedback about the current leg alignment and knee gap kinematics.

Patients
15 patients could be included in our first clinical trial. All patients showed severe osteoarthritis of the medial compartment with an intact lateral compartment. Preoperative mechanical leg alignment values ranged from 8° varus to 2 ° varus. All operations were performed by one surgeon (AP) under a combination of peridural and femoral block anaesthesia. A tourniquet was used in all cases. Recorded intraoperative parameters included: total operation time, time of robotic use, tourniquet time and all robotic related parameters.
Results: The utilization of the MAKO system did work in all cases. Not technical failures or problems occurred. At first follow up visit after 6 weeks no complications occurred. The set up time for the robot (before the operation starts) was 38 minutes. Time for the robot assisted burring itself needed in average 34 minutes (29-50 min) Average time for the intraoperative registration process needed 7.5 minutes (6-12 min). The overall operation time was 132 minutes (92-142 min). The mean torniquet time was 87.4 minutes (68-113 min). In all patients the planned and intraoperative confirmed tibiofemoral angle in the coronal plane was within 2° (± 1.3). The average stay in hospital was 2.2 days. Values for the range of knee motion after 6 weeks were mean flex/extension: 115/3/0°. The length of skin incision was averaged at 6cm. Postoperative long leg axis radiographs were within 1.7° (±2.1).

Discussion: Relevant parameters for UKA, as leg alignment and especially precise implant placement can be actively controlled intraoperative with the help of a semi-active robotic system. The individual burring, with a tactile guidance system, of the predefined bony area of interest, allows for a complete new bone conserving technique for UKA. A valuable combination of a minimal invasive technique under surgeon controlled robotic assisted implant placement becomes available. The chances for good and reproducible long term clinical results might therefore be higher than with conventional techniques. Following prospective clinical studies will have to improve our initial findings.
Does Medio-Lateral Motion Occur In Normal And Cruciate-Retaining And Posterior-Stabilized Replaced Knees?

BELVEDERE C1, LEARDINI A1, ENSINI A2, FELCIANGELI A2, BIANCHI L2, CATANI F2, GIANNINI S2

1 Movement Analysis Laboratory, Istituti Ortopedici Rizzoli, Bologna, Italy
2 Department Of Orthopedic Surgery, Istituti Ortopedici Rizzoli, Bologna, Italy

Introduction: A comprehensive analysis of the complex tibio-femoral joint (TFJ) motion is necessary to better understand intact joint function and to enhance the design of prosthesis components in total knee arthroplasty (TKA) [1]. Complete three-dimensional tibio-femoral contact data in TKA, including also both the antero-posterior and medio-lateral joint translations, may provide a new insight for determining tibial bearing wear patterns in-vivo and, thus, for re-designing the prosthetic articulating surfaces [2]. Many previous studies, both in-vivo and in-vitro, have dealt with only joint rotation, contact point location, antero-posterior sliding and rolling, nearly disregarding possible medio-lateral joint translation. In many of the current designs this motion is prevented or constrained. Computer-aided surgery has recently introduced knee navigation systems in TKA. These are able to monitor, with a good level of accuracy, all six degrees of freedom of TFJ kinematics during all phases of TKA and to improve prosthesis component positioning [3]. In case medio-lateral joint translation is demonstrated to be important for normal knee joint function, TKA designers should consider this new feature cautiously. Furthermore, because current knee surgical navigation systems are able to track TFJ motion, surgeons might want to look carefully at restoration of this translation intra-operatively. The purpose of this study was to analyse in-vitro knee kinematics both at the intact joint and after TKA with two different prosthesis designs particularly focussing on the possible medio-lateral TFJ translation. A surgical knee navigation system was used as measurement system.
**Materials and Methods:** Sixteen fresh frozen amputated legs with the knee free from anatomical defects, with intact joint capsule and quadriceps tendon were analyzed using a surgical navigation system (Stryker® Knee Navigation System, Kalamazoo, MI-USA). Clusters with active markers were pinned on the femur and tibia to track these bones. The standard pointer was used for system control and landmark digitations, used for femoral and tibial anatomical reference frame definition according to recommended definitions [4]. Particularly, the femoral and tibial reference frame origins were located on two points, directly digitized respectively on the knee centre (KC), i.e. the most distal point of the femoral groove, and on the centre of the tibial plateau (CT), i.e. the deepest point in the sulcus between the medial and lateral intercondylar tubercles. Series of five trials of manually driven knee flexions in a 0°-140° arc were performed at the intact and replaced knees under condition of 100 N vertically applied at the quadriceps.

Measurements were performed at the intact knees and after TKA, eight with cruciate-retaining (CR) and eight with posterior-stabilized (PS) prostheses (Scorpio®, Stryker Orthopaedics, Mahwah, NJ-USA).

TFJ flex-extension, intra-extra rotation and ad-abduction were calculated according to a standard mechanical joint convention [5]. KC translations were calculated with respect to the tibia reference frame. Furthermore, standard deviation (SD) and mean values for all kinematic variables were calculated for each group of trials at each degree of TFJ flexion.

**Results:** As for the general data quality, intra-specimen repeatable paths of motion over repetitions and coupled path of motion throughout the TFJ flex-extension cycle were observed in intact and replaced knees (average SD < 0.7° and 0.5 mm, respectively for all rotations and KC translations). The mean difference over the 0°-140° knee flexion arc between the intact and replaced knee, was smaller than 4.0° for all three TFJ rotations. For all three KC translations, these differences were 1.9 mm anterior, 1.2 mm proximal, 5.0 mm lateral in CR-TKAs. These were 0.2 mm posterior, 2.0 mm distal, 0.7 mm lateral in PS-TKAs. As for the issue of this study, the average interval in the examined TFJ flexion arc of the medio-lateral KC translations were: from 8.7 mm medial to 6.6 mm lateral in the intact knee, from 0.2 mm medial to 8.0 mm lateral in CR-TKA, from 4.4 mm medial to 4.0 mm lateral PS-TKA. In the figure, the mean values of KC projection over specimens in 0-140 knee flexion arc are reported on tibial transverse plane (the silhouette of the tibial prosthesis component is also shown to help understanding).
Discussion: Considerable lateral KC translation occurs during normal knee flexion. After TKA, this translation is restored better by PS prosthesis design than by CR prosthesis design, where it is laterally shifted respect to that in the natural knee. Medio-lateral translation has not been reported with sufficient extent so far in the literature, and apparently even not considered in many TKA designs.

The knowledge of this translation can enhance further the comprehension of the intact and replaced knee kinematics and improve TKA prosthesis design. Computer navigation systems seem to be accurate enough to track intra-operatively this motion.

References
Defining The Ideal Patellar Resection Plane

Anglin C1, Fu C1, Hodgson AJ2, Helmy N3, Greidanus NV2, Masri BA2

1 University Of Calgary, Calgary, Canada
2 University Of British Columbia, Vancouver, Canada
3 Uniklinik Balgrist, Zurich, Switzerland

canglin@ucalgary.ca

Introduction: Asymmetric resection of the patella during total knee arthroplasty (TKA) results in different medial and lateral bone thicknesses, which has been associated with significantly higher rates of anterior knee pain as well as postoperative problems such as bony impingement, maltracking and patellar fracture.

The two most common recommendations for the ideal mediolateral patellar resection plane are: 1) parallel to the anterior surface [ANT]; and 2) from the medial to the lateral extents [MLE]. However, in many cases these definitions differ from one another and it is unclear which is better; there has also been no acknowledgement of the variability in defining the MLE line; and finally, “parallel to the anterior surface” is a purely qualitative definition since the surface is not flat and is often quite curved or irregular.

The senior author (BAM) devised a method, called the medial-divot method [MD], in which he identified a divot (slight depression) on the medial side on the preoperative radiograph and drew the desired resection line; intraoperatively, he found the divot and attempted to repeat the radiographically-drawn resection on the bone. A fourth option (proposed by co-author NVG) was to define the ideal plane perpendicular to the thickest anteroposterior cross-section [PERP]. This definition is equivalent to applying parallel-edge calipers to the patella and may reflect the tilt under loadbearing.

Computer-assisted surgery (CAS) systems already exist for placing the femoral and tibial components in TKA. However, no CAS systems currently provide guidance to the surgeon in performing the desired patellar cut. To implement an
ideal resection plane in a CAS system, it is necessary both to define the plane quantitatively and to know how much variability exists within and between definitions of the ideal resection plane.

The objectives of this study were therefore to: (1) determine the intra- and inter-surgeon repeatability in drawing MLE and MD lines on preoperative radiographs; (2) determine angular differences between the mean surgeon-specified lines (MLE and MD) and the two lines calculated from the digitized geometry (ANT and PERP), and (3) compare the postoperative resection line to the four definitions, before and after implementing the MD method.

**Materials and Methods:** Institutional review board approval for this study was obtained. Forty sequential preoperative and postoperative axial (‘skyline’) radiographs were obtained from the senior author’s TKA patients; the first twenty predated his adoption of the MD method while the second twenty came from immediately after he started using this method.

The preoperative X-rays were presented in randomized order to three experienced surgeons, who used a custom digitization program (a macro implemented in ImageJ, NIH, USA) to digitize either the MLE or MD line on all X-rays, and then the alternative line on all X-rays (without seeing the previous line). Three X-rays were selected to be repeated 10 times each, randomly interspersed in the data set. One of the surgeons (NH) digitized the circumferences of all the patellae, including the resection plane.

For the analysis, the x-y line coordinates were used to determine the MLE and MD angles; ANT25/75 and ANT33/67 were calculated from a least-squares fit to the points along the central portion of the anterior surface (25-75% or 33-67% of the horizontal distance); PERP was calculated by finding the angle that minimized the distance between two parallel lines tangent to the anterior and posterior surface of the patella. All calculations were done using Matlab. MLE and MD standard deviations were tested for statistical differences using an F-test; angles were compared using Student’s t-tests. To match the postoperative resection line to the preoperative radiographs, we computed the optimal translations, rotation and scaling for mapping the postoperative anterior patellar contour to the preoperative image.

**Results:** For each individual surgeon, the repeatability of drawing the resection line on the same image using the MD method was significantly better than that of the MLE method (p<0.001), with the standard deviation of the MD
method (0.8°) being half that of the MLE method (1.6°). Between surgeons, MD was also significantly more repeatable than MLE with standard deviations of 1.4° and 2.0° respectively (p<0.001). The MLE, MD and ANT definitions were usually similar and had no consistent directional bias (mean difference from MLE, 0.02°, SD, 2.3°). PERP was often quite different and biased towards medial under-resection (mean difference from MLE, 8.3°, SD, 5.6°) (Figure 1). For the first 20 cases after adopting the MD method clinically, the resection plane led to greater medial under-resection relative to the anterior surface (mean 5.4° vs 1.7°) (p=0.03). When the resection plane differed from the 3 main definitions, it typically aligned with the PERP definition.

Discussion: In the past, measures of radiographic tilt or the resection plane have been compared to a single “patellar horizon” which was not precisely specified or characterized. It is clear from the present study that there is considerable variability in this definition, ranging up to an 11° difference between surgeons, or even up to 8.5° within a single surgeon. Using the medial divot definition to draw the desired resection plane provided a much more repeatable definition which was still similar to the mediolateral extents and anterior surface definitions. The anterior surface definition is the most likely to lead to equal medial and lateral thicknesses, depending on the points chosen, since the thicknesses are by definition measured from the anterior surface. Since the cases of medial under-
resection following adoption of the MD method may be related to the initial learning curve, we will repeat the analysis for the latest 20 cases (not in the current data set). Implementing the MD method, which was the most repeatable radiographic definition, in a CAS system may achieve the most predictable resection plane, resulting in similar medial and lateral thicknesses and thereby possibly reducing the postoperative incidence of anterior knee pain. Our results represent the first analysis that we are aware of regarding the variations and repeatability of different patellar resection definitions and may therefore offer guidance for both conventional and computer-assisted surgery.

References

Assessment Of Anatomical Criteria Across Populations Using Statistical Shape Models And Level Sets

KOZIC N¹, REYES M¹, TANNAST M², NOLTE LP¹, GONZÁLEZ BALLESTER MA¹

¹ MEM Research Center, ISTB, University of Bern, Switzerland
² Department Of Orthopaedic Surgery, Inselspital, University Of Bern, Switzerland

Nina.Kozic@MEMCenter.unibe.ch

Introduction: Statistical shape models have been widely used for image segmentation and shape estimation from sparse sets of landmarks [1,2]. Existing works on optimisation in shape space aim at finding a single instance from the statistical shape model that best approximates the input data, subject to some regularisation constraint. In certain cases, it may be interesting to find all instances of the shape model that meet a certain criterion. For example, one may be interested in estimating which range of population falls within a given anatomical criterion, thus establishing a partition of the shape space into “valid” and “invalid” shapes. In this work, we propose a method for global optimisation of shape constraints that effectively finds all instances in the PCA (principal component analysis) shape space that meet a certain criterion. We validate our method by an application to shape analysis of human femora, in particular femoral inclination, and analyzing which range of population has a femoral inclination similar to a given implant.

Materials and Methods: The method is based on level sets in the parametric shape space defined by PCA. PCA is a multivariate factor analysis technique aiming at finding a low-dimensional manifold in the space of the data, such that the distance between the data and its projection on the manifold is small [3]. We use PCA to compute a statistical description of the shape model and to obtain the average vector of the positions and the principal modes of variation. Considering a shape space as a weighted linear combination of the eigenvectors, each element / shape in this shape space can be defined by a set of coefficients $\alpha_1, \ldots, \alpha_L$ (Figure 1a). We define as well a scalar mapping $M$ that can be any
measure derived from the shapes in the PCA shape space, and can represent a clinically meaningful pathoanatomical criterion. Our goal is to find all instances in the shape space that meet a certain criterion dependent on a scalar measure $M$.

The level set segmentation allows for the representation of objects with complex topologies [4,5] and in our application it can be used to identify disconnected subsets of the shape space that meet the criterion. In order to segment the observed space $M$ we propose to minimize the energy functional, which represents the boundary force that attracts the evolving surface towards a predefined segmentation constraint $M = \text{const}$, while keeping the surface smooth. The zero level set computation is further optimised using automatic seed initialisation and narrow band level set evolution [6].

**Results:** We present results obtained from a training set of 30 surface models of complete left human femora extracted from CT data. Correspondences across data sets were established with a Spherical Harmonic based shape representation method and further optimized via a Minimum Description Length optimization [2]. The average shape was computed by simple averaging of corresponding landmarks across the data sets. The remaining variation was analyzed by PCA (Figure 1b). We retain the first three principal components, which account for 89.22% of shape variability in the population. In our case, we use the range $-3 \leq \alpha_i \leq 3$ for every shape coefficient. This accounts for 99.7% of the shape variability encompassed in each principal component.

The clinical measure of interest is defined as the femoral inclination of the generated instance mesh: $M = \text{FIA}(\alpha_1, \alpha_2, \alpha_3)$. Femoral inclination is defined as frontal plane alignment of femoral head and neck relative to shaft, and is commonly employed in clinical practice as a descriptive parameter. In normal adults, the neck of the femur forms an angle of from 126 degrees to 128 degrees with the shaft, and any big variation from this value results in hip deformations. We generate our scalar 3D map by computing FIA values, and the obtained range of femoral inclination from 125.5 to 145.6 degrees correlates well with previous studies [7]. Following the specifications for the Omnifit EON femoral stem implant design by Stryker we compute the set of bones that have the neck angle of $M = 127 \pm 2.5\,^\circ$. The mapping function characterizes the spectrum of shapes that have a similar range of the femoral inclination (Figure 1c).

**Discussion:** The method for optimisation in PCA shape space allows to find a partition of the shape distribution into regions that meet / do not meet a
given criterion. Although the example has been elaborated for 3D maps, the method is applicable to maps of any dimension, determined by the number of principal components retained. To our knowledge, this is the first research into the problem of finding all instances in a shape distribution meeting a given criterion. The practical use of such a concept is of extreme importance in the study of the anatomical evidence of a pathology, or the morphologic features in implant positioning.

References


CT - 3d Fluoroscopy Image Fusion As A Non-Invasive Registration Method For Pelvic Trauma Surgery: An In-Vitro Evaluation

RUDOLPH T¹, CITAK M², HOFNER T², KOWAL J¹

¹ MEM Research Center, ISTB, University of Bern, Switzerland
² Trauma Department, Hannover Medical School, Germany

tobias@memcenter.unibe.ch

Introduction: Navigated three-dimensional fluoroscopy devices such as the Siremobil Iso-C3D (Siemens Medical AG, Erlangen, Germany) have been shown to be a powerful imaging modality in orthopedic trauma surgery [1]. The implicit registration of Iso-C3D volumes allows for a navigation accuracy of 1.0 mm to 1.5 mm [2]. It has further been demonstrated that the registration of preoperative computed tomography (CT) data sets by means of fusion with the intraoperative Iso-C3D image volume can provide improved visualization of the surgical site at a resulting navigation accuracy of between 0.6mm and 1.5mm [3].

The application of a CT-Iso-C3D image fusion based registration to pelvic trauma surgery seems desirable as it would allow for a non-invasive method to register complex, and difficult to access, anatomical structures. In order to evaluate the clinical feasibility of the complete registration procedure, three test cases have been identified. A transverse acetabular fracture, a vertical sacral fracture and a non-fractured sacroiliac joint. Registration of fractured structures poses special challenges as it requires a piece-wise rigid image fusion method. By using full body cadaveric specimens, the proposed registration method can be evaluated in a clinically relevant setup.

Materials and Methods: Two fresh human female full body specimens were used for the experiments. Both specimens were osteoporotic and had a one-sided hip prosthesis. An experienced trauma surgeon created a transverse acetabular fracture as well as a vertical fracture of the sacrum in each specimen.
Both specimens were CT scanned with a slice distance of 0.4 mm and a slice thickness of 0.625 mm. The CT data sets were segmented and a surface mesh was generated. The experimental setup consisted of a Siremobil Iso-C3D equipped with a BrainLAB “Fluoro 3D/2D Registration Kit” (BrainLAB AG, Feldkirchen, Germany). The specimens were instrumented using passive tracking sensors carrying retroreflective spheres. The optical tracking system used was a NDI Polaris Spectra system (Northern Digital Inc., Waterloo, Ontario, Canada). The employed navigation software is based on the MARVIN framework [4], running on a standard personal computer. Registration of the CT scan to the Iso-C3D image volume was accomplished in a two-step process. First, the data sets were roughly aligned using a coarse paired-point matching. Afterwards, the optimization of the matching was achieved by maximizing the “Normalized Mutual Information” between the data sets [5]. The data range used for calculating the mutual information metric was restricted to values specific to bone. For the CT scans, this is easily achieved using the Hounsfield scale. For the Iso-C3D scans, this had to be done manually by means of visual inspection. In order to establish a piece-wise rigid registration, the CT scans were masked using the (preoperative) segmentation data. Every fragment was registered separately. The accuracy of the registration method was measured by collecting up to 50 surface points for each fragment, using a standard surgical pointer. The distances from the transformed digitized points to the extracted surface data serves as the error measurement. Since the sacroiliac joint was not directly accessible, points were collected from the pelvic wing. The advantage of such a method is its applicability in a clinical trial with a very limited physical access to the surgical area.

Results: Table 1 lists the averaged mean errors and standard deviations for the conducted co-registration experiments. In case of the transverse acetabular fracture in specimen 1, the inferior fragment (ischium and pubis) could not be navigated because of technical issues. For every experiment, six to ten Iso-C3D scans were used. The bone quality was poor in both specimens due to advanced osteoporosis. This has a direct impact on the performance of the image fusion algorithm, because it reduces the soft tissue/bone contrast considerably. However, all scans could be used for image fusion.

Discussion: This study presents first evaluation results of a CT-3D Fluoroscopy co-registration procedure based on piece-wise rigid 3D/3D image fusion. The trials were carried out within a clinically realistic setup using a navigated Iso-C3D. Additionally, by directly measuring the errors using a standard surgical pointer, the presented error measurements provide meaningful insights
concerning the obtainable navigation accuracy in a clinical situation. The trials revealed an accuracy close to the base accuracy of direct Iso-C3D navigation. The experimental results show that the proposed registration method can be applied to the chosen surgical scenarios and encourage its application in a clinical test. Furthermore, the procedure is not limited to the Iso-C3D, but can also be used in combination with any other directly navigated three-dimensional fluoroscopy system.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>SI joint, intact</th>
<th>SF fracture, SF</th>
<th>SI fracture, WF</th>
<th>Acetab. fracture, IF</th>
<th>Acetab. fracture, WF, SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.78 (0.75)</td>
<td>0.46 (0.37)</td>
<td>0.68 (0.55)</td>
<td>1.01 (0.94)</td>
<td>1.05 (0.37)</td>
</tr>
<tr>
<td>2</td>
<td>0.94 (0.6)</td>
<td>1.57 (0.64)</td>
<td>0.34 (0.27)</td>
<td>1.6 (1.16)</td>
<td>1.05 (0.37)</td>
</tr>
</tbody>
</table>

Table 1: The averaged mean errors and standard deviations (in brackets) are given in millimeters. The abbreviations are: SF=sacral fragment, WF=wing fragment, IF=inferior fragment, SF=superior fragment.

References
Pet-CT-Fluoro-Matching On Long Bones? - First Experiences

Militz M¹, Hungerer S¹, Haug A²

¹ Bg Trauma Center, Murnau, Germany
² Department Of Nuclear Medicine, Ludwig-Maximilians-University, Munich, Germany

mmilitz@bgm-murnau.de

Introduction: Is it possible to match the PET-CT-Data-Set in the OR with fluoro images of long bones?

Materials and Methods: In preparation for a surgical investigation of patients with chronic osteitis of the femur, a dataset of a PET-CT was created. Three patients with a history of a chronic osteitis were asked to agree to the use of a navigated operative procedure in order to detect the infected focus at the femur in the OR and to remove it. For evidence of the osteitis, microbiologic investigation was performed.

In the first step, the PET-CT-Data-Set was imported into the software of the navigation system. The import of the PET-CT-Data into the navigation system was achieved by using the licensed software to create a compatible data-set. In the OR, the registration of the patient’s femur was carried out with a reference marker fixed at the tibial tuberosity with a bandage. The patient was placed in dorsal position, and the affected leg was stabilized. The fluoro images were taken by a calibrated image intensifier. For the CT-Fluoro-matching, a prominent bone structure at the distal end of the femur was chosen. With the virtual bone structure visible on the navigation screen, the surgical approach could be minimalized. The removal of the infected bone focus was performed using a navigation-guided hollow drill. During the drill procedure X-Ray shots were taken to control the position of the instrument.

Results: All three patients were treated successfully with the described procedure. The accuracy of the virtually-shown position in relationship to the real position of the navigation-guided instrument was excellent. By preventing movement during the operative procedure, the fixation of the reference marker
at the tibial site was associated with high accuracy. With the help of the visualized virtual position of the focus in the bone, the planning of the surgical approach was possible and therefore minimized. In all cases the microbiologic investigation shows growth of germs as the evidence for the PET-CT as the method of choice to detect an infected focus in the bone and the possibility of using the obtained dataset for intraoperative orientation. The verification of the image accuracy on the navigation display showed no deflection of the actual placement of the navigated instrument, because the position of the focus of osteitis was checked with an X-Ray shot.

Discussion: In this examination we explored, whether PET-CT data can be imported into a conventional optical navigation system and can be edited for referencing purposes. The matching of the CT-dataset with the fluoroscopic images of the image intensifier was feasible, without any accompanying problems. Despite the noninvasive fixation of the reference marker, the optical verification of the accuracy showed no deflection of the displayed position of the navigated instrument when compared to the actual placement of the focus of osteitis.

Since the PET-CT data provide, in addition to the information about the localization, also information about the activity of a pathological focus, the navigated rehabilitation of foci of osteitis in long hollow bones is possible. For successful treatment and salvage of chronic osteitis, the implementation of navigated surgical tools can reduce the dimension of the surgical approach and limit bone damage without reducing the surgical goal. Additionally, with other pathological processes that can be diagnosed with PET-CT, a navigated resection for the reduction of the resection extension is reasonable. Further clinical applications must determine whether the possibilities established experimentally can be implemented effectively in practice.
A Prospective Study On Navigated High Tibial Osteotomy

GEBHARD F, KEPPLER P, IMHOFF AB, STÖCKLE U, GRÜTZNER PA, HOFNER T, LJUNGQVIST P, KRETTEK C

1 Department Of Orthopedics And Traumatology, University Ulm, Germany
2 Department Of Sport Orthopedics, University Hospital Rechts Der Isar, Munich, Germany
3 Department Of Traumatology, University Hospital Rechts Der Isar, Munich, Germany
4 Department Of Traumatology, Katharinenhospital Stuttgart, Germany
5 Department Of Traumatology, Hannover Medical School, Germany
6 AO Clinical Investigation And Documentation, Davos, Switzerland

p.keppler@t-online.de

Introduction: Today it is generally accepted, that the long term results of HTO are dependent on the mechanical leg axis. It is also undisputed that intraoperative navigation significantly decreases the range of the mechanical leg axis in TKA. Therefore the aim of this prospective HTO study was to evaluate the precision of the postoperative mechanical leg axis in terms of deviation from the planned leg axis in long standing x-rays.

Materials and Methods: Six clinics participated in the prospective study. The inclusion criteria were active adult patients, medial gonarthrosis of congenital or posttraumatic genu varum, intact lateral joint compartment, physiological age-appropriate ROM in knee joint of the affected leg. The exclusion criteria included, besides general contraindications for an elective operation, a BMI >35 and drug or alcohol abuse.

After preoperative planning a fax with the calculated mechanical leg axis was sent to AO - Clinical Investigation and Documentation (AOCID), Davos Switzerland.

In all cases a medial open wedge osteotomy without any bone grafts or bone ceramics was performed. The internal fixation of the HTO was done with the Tomofix® implant. During the operation the mechanical leg axis was adjusted according to the preoperative planning with the help of an imageless navigation.
system. After 6 weeks a long standing full weight-bearing x-ray was done to control the mechanical leg axis again. The postoperative measurements on the x-ray were performed by AOCID.

**Results:** From 1/06 to 12/07 59 patients fulfilled the inclusion criterions. Seven patients were excluded from the study due to major protocol violations. Of the final 52 patients 49 patients (94%) had a complete follow up. The maximum deviation between the preoperative planning and postoperative result was 4°. In 45 patients the maximum deviation was 3° (92%) and in 34 patients the maximum deviation was 2° (69%).

**Discussion:** According to the studies of Fujisawa et al, Dugdale et al and Hsu et al, the load of the medial knee compartment and therefore the long term results after HTO are dependent on the mechanical leg axis. To our knowledge this is the first prospective study where a navigation system was used to control the mechanical leg axis. The particular study design shows the real benefit of the navigation system in this type of HTO. The range of the mechanical leg axis is comparable with the range of the mechanical leg axis after navigated TKA. Up to now there is no HTO study without navigation with a similar study design. In most studies the postoperative mechanical leg axis is explained by a not clearly defined arthroscopic knee result. Therefore the presented study is a basis for the accuracy of further navigated and conventional performed HTO.

**References**


Open Wedge Tibial Osteotomies-Influence On Axial Rotation And Tibial Slope

KENDOFF D¹, LO D¹, GOLESKI P², WARKINTINE B⁴, O’LOUGHLIN P¹, PEARLE A¹

¹ Hospital For Special Surgery, New York, USA
² University Of Michigan Medical School, Ann Arbor, MI, USA
³ Brainlab, AG, Heimstetten, Germany

Introduction: Inaccurate coronal plane and inadvertent sagittal plane realignment is a common problem after high tibial osteotomies (HTO). While the effects of a HTO on the coronal has been extensively studied, influence on the axial rotation has not been described adequately. The current study examines the effect of HTO on tibial rotation in the axial plane as determined by computed tomography. We hypothesised 1) that high tibial osteotomies have an effect on tibial rotation in the axial plane, 2) depending on the predefined osteosynthetic implant used a corresponding change of the tibial slope would occur.

Materials and Methods: Eight fresh-frozen cadaveric hemi-torsos including pelvises and bilateral lower extremities (13 legs) were used. Two legs were unsuitable due to prior surgery, while a third was rejected because of limited bone quality. The cadavers had no history of prior surgery, injury or arthritic changes affecting the lower extremities.

Experimental Protocol

To ensure consistent alignment during pre-operative, postoperative and CT measurements, self-expanding foam molds were created to hold each leg at 0° of femoral-tibial rotation and full extension with a consistent gravitational force on the knee during data acquisition (Figure 1). Reference arrays for navigated determination of the dynamic leg alignment were applied. Two surgeons performed navigated HTOs on each of the specimens and recorded pre-operative and postoperative alignment with a conventional navigation system. (BrainLAB, Germany). All osteotomies were fixated using...
a 12.5 mm tapered Puddu plate placed centrally in the osteotomy (Arthrex, FL/USA), with two cortical screws and two cancellous screws (Figure 3). We ensured reproducible plate placement by using defined distances from the tibial tubercle, before plate fixation. In three cases, cement was packed around the plate in the wedge to ensure stable fixation and allowed to harden before further manipulation. The parameters recorded via the navigation system were varus-valgus angle and change in posterior slope.

CT measurements
All limbs were CT-scanned using a Lightspeed VCT (GE Medical Systems, Buckinghamshire/UK) before and after HTO, with image slices taken 2.5 mm apart at three sites: hip, knee and ankle. The CT data was then converted into 3D computer models of the hip, knee and ankle using Mimics 10.11 software (Materialize, Leuven/Belgium) (Figure 4). Landmark points were placed directly on the surface of the 3D models and verified by visual inspection of the CT slices.

Using a spherical-center tool, landmark center points of the femoral head and distal femoral condyles were calculated (Geomagic). This was performed in order to obtain values for femoral length and anteversion. From both types of models, the following parameters could be measured both pre- and postoperatively:

- varus-valgus leg alignment
- tibial axial rotation
- tibial slope including determination of lateral and medial tibial slope
- leg length including determination of femoral and tibial length

Statistical Analysis
The statistical software used for all analyses was SPSS 15.0 (SPSS, Chicago/USA). We used a paired student’s t-test with a p value of less than 0.05 regarded as indicative of statistical significance.

Results: Varus valgus leg alignment
The varus-valgus alignment was statistically different (p<0.005) between pre- and post-op groups due to the insertion of the tapered plate. Each limb had an average increase in valgus angulation of 11±4.7°.

Tibial rotation
The average values for pre- and post-op axial tibial rotation were 26±10° and 28±7.3°, respectively. The distal tibia was externally rotated with respect to the proximal tibia in 10 of the 13 limbs. The average rotation increased by 2.7±6.3°, (max 12° external rotation, maximum 9.5° internal rotation). However, there was not a statistically significant difference when compared to the pre-op group (p=0.075).
Tibial Slope

Averaging the tibial pre- and post-op slope groups revealed a difference of 4.2±5.9°. This proved to be statistically significant (p<0.025). The average pre-op lateral and medial tibial slopes were 4.6±5.0° and 5.6±3.6°. The post-op lateral and medial tibial slopes were 0.8±7.6° and 1.0±7.7°, respectively. The post-op lateral tibial slope was significantly different from pre-op (p<0.05) with an average 3.7° increase in anterior tilt. 10 of 13 limbs exhibited this increase in anterior tilt. Similarly, the medial tibial slope exhibited a significantly difference from pre-op (p<0.005) with an average 4.6° increase in anterior tilt. Again, 10 of 13 limbs exhibited this increase in anterior tilt, though not necessarily within the same limb as the lateral group.

Leg length

Landmarks selected by CT showed that the length of the femur did not significantly change after HTO (-0.5±1.3mm). This result confirmed the accuracy of our CT measurement protocol. The length of each tibia significantly increased after HTO by 7.1±3.7mm (p<0.005), though there was no significant change in overall leg length.

**Discussion:** In summary tibial rotation does occur in high tibial osteotomies with a higher tendency to external rotation without significance. Tapered implants do not guarantee a retaining tibial slope, while tibial length significantly changes of HTO. The combined use of CT and 3-D software measurement techniques is reproducible and can be used without any further invasive fixation devices.
Closing Wedge Proximal Tibial Osteotomy Using Navigation System

BAE DK, SONG SJ, NOH JH, CHANG WS, EO JH

Department Of Orthopedic Surgery, School Of Medicine, Kyung Hee University, Korea

tesstore@empal.com

Introduction: To compare the radiographic measurement and intra-operative measurement under navigation system in computer assisted closing wedge proximal tibial osteotomy and to evaluate the accuracy of the navigation system.

Materials and Methods: From July 2005 to November 2007, fifty one closing wedge proximal tibial osteotomies were performed with a CT-free navigation system (Vector Vision® version 1.1, BrainLAB, Heimstetten, Germany), and they were prospectively analyzed. Fifty cases had medial compartment osteoarthritic knees with varus deformities, and one case had genu varum. Forty seven cases were female and four were male. The mean age was 60.1 years (range, 27 to 71 years). The mean body mass index was 24.9 kg/m² (range, 17.3 to 31.1 kg/m²). Surgery was performed in the same manner for all patients by one experienced surgeon. The postoperative mechanical axis percentage (MA%), which is planned to be made on the navigation system, was 62%. The osteotomy site was fixed with a miniplate staple. The postoperative radiographs were taken on 10 days after the surgeries. The mechanical axis (MA) was defined as the angle between the femoral and tibial mechanical axis on an orthoroentgenogram. The MA% was defined as the percentile denotation of the point at which the mechanical axis of the low extremity intersects the line extending from the medial border to the lateral border of the tibial plateau on an orthoroentgenogram. The femorotibial angle of the lower limb was measured by Bauer’s method on a standing anteroposterior radiograph and the posterior slope angle of medial condyle of tibia was measured by Oswald’s method on a true lateral radiograph.

Radiographic measurement was performed on the picture archiving and communication system (PACS) by two independent observers. The MA and
MA% were measured with a navigation system intraoperatively, and they were compared with radiographic measurements. Pearson correlation test (SPSS 12.0) was utilized for statistical analysis.

**Results:** On the radiographic measurement, the preoperative MA and MA% measured by observer 1 were varus 7.6 ± 2.7° and 15.9 ± 11.4%, respectively, and the postoperative MA and MA% were valgus 1.6 ± 2.7° and 56.7 ± 11.9%, respectively. The pre- and postoperative femorotibial angle were varus 0.8 ± 2.5° and valgus 8.4 ± 2.8°, respectively. The posterior slope of medial condyle of tibia was 11.0 ± 2.8° preoperatively and 9.0 ± 2.7° postoperatively. The difference in the posterior slope angles was 2.0 ± 2.0°. The preoperative MA and MA% measured by observer 2 were varus 7.7 ± 2.7° and 16.2 ± 11.6%, respectively, and the postoperative MA and MA% were valgus 1.6 ± 2.7° and 56.7 ± 11.8%, respectively. The pre- and postoperative femorotibial angle were varus 1.0 ± 2.5° and valgus 8.4 ± 2.7°, respectively. The posterior slope angle of medial condyle of tibia was 11.0 ± 2.6° preoperatively and 9.1 ± 2.9° postoperatively. The difference in posterior slope angles was 1.9 ± 2.2°. There were positive correlations between the measured angles by two observers (p<0.01). On a navigation system, the mechanical axis before osteotomy was varus 8.4 ± 2.6°, and the MA and MA% after fixation with the miniplate staple were valgus 3.5 ± 1.4° and 62.0 ± 6.0%, respectively. There were positive correlations between the radiographic measurements and measurements with the navigation system (p<0.05).

**Discussion:** There were significant correlations between the values measured on the navigation system and radiographs in a closed wedge high tibial osteotomy using a navigation system. For treatment of medial compartment osteoarthritis of the knee, the closing wedge proximal tibial osteotomy using the computer assisted navigation system is a reliable method because the correction angle is able to be checked in real time, to be predicted, and to be controlled during the operation.
Navigated Rotational Acetabular Spherical Osteotomy

SUGANO N1, NISHII T1, SAKAI T1, TAKAO M1, HANANOUCHI T1, KOYAMA T2, SATO Y3, NAKAMURA N4

1 Department Of Orthopaedic Surgery, Osaka University Graduate School Of Medicine, Japan
2 Department Of Orthopaedic Surgery, Osaka-minami Medical Center, Japan
3 Division Of Image Analysis, Osaka University Graduate School Of Medicine, Japan
4 Department Of Orthopaedic Surgery, Kyouwakai Hospital, Japan

sugano@ort.med.osaka-u.ac.jp

There are several types of acetabular redirection osteotomies such as Wagner, Eppright, Tagawa, and Ganz. These aim at reducing the contact pressure in the hip joint and the prevention of progressive subluxation to halt osteoarthritic changes in hip dysplasia. There are, however, some differences among these osteotomies. One is the design of osteotomy which influences the bone contact area and the stability of the osteotomy site. The direction of acetabular movement is also different and it affects the postoperative range of motion and the vulnerability to femoro-acetabular impingement. Wagner developed three types of acetabular osteotomies and Type 1 and Type 2 are quite similar to Tagawa’ rotational acetabular osteotomy. These osteotomies move the acetabulum antero-laterally, but the direction of rotation has not been well defined. Eppright developed the Dial osteotomy which cuts the acetabular fragment with a hemi-circular saw through an anterior approach and rotates the fragment only laterally. He thought that lateral rotation also increased the anterior bony coverage. Ganz developed a different cut design for the periacetabular osteotomy to avoid complications such as avascular necrosis of the acetabulum and the secure internal fixation using screws allows early mobilization. The acetabular fragment is moved antero-laterally. When reductions in the peak contact pressure in the hip joint based on various directions of rotation are simulated, anterior rotation of the acetabular showed a larger effect on reducing the contact pressure while walking than lateral rotation1). But, it increased the peak contact pressure while stair climbing. Too much anterior rotation reduces
acetabular anteversion and increases the likelihood of impingement when bending the hip. To obtain the most natural hip after acetabular osteotomy, we started to use CT-based navigation. The purpose of this study is to evaluate the clinical results of our navigated rotational acetabular spherical osteotomy (RASO). Since 1999, 26 females with painful hip dysplasia underwent RASO using navigation. The age at operation was 30 years on average with the range from 17 to 44 years. On preoperative x-rays, CE angle ranged from -19 degrees to 12 degrees with an average of 0 degrees. Based on preoperative CT images, 3 dimensional planning was made as follows. A sphere is fit to the femoral head to determine the hip center. The diameter of the sphere was increased by 20mm for osteotomy design. This sphere size keeps a sufficient thickness of the acetabulum and the sphere was moved up to 5mm antero-medially to avoid thinning of the posterior column and to medialise the hip center. The acetabular fragment was rotated laterally and anteriorly until lateral CE angle reached to 35 degrees with a ratio of three to one of lateral to anterior rotation. This ratio kept the acetabular anteversion unchanged. In the OR, the patients were placed in a lateral decubitus position and a transtrochanteric approach was used. A curved osteotome with LEDs was used and the position of the osteotome was tracked in real time on the navigation display after surface registration of the pelvis. The patients were followed-up for average 3 years. There were no complications such as infection, none-union, avascular necrosis and neurovascular injuries. The average JOA hip score improved from 75 preoperatively to 98 at the latest follow-up. No one showed limping. Radiographically, postoperative CE angle was 35 degrees with the range of 13 to 53 degrees. In two cases, a slight narrowing of the joint space was seen. The remaining cases showed no progression of osteoarthritis. We conclude that our navigated RASO is safe and effective for the treatment of painful hip dysplasia.
Computer-Assisted Detection Of Radiographic Parameters Predicting Poor Long-Term Outcome Of Bernese Periacetabular Osteotomy

Steppacher SD¹, Tannast M¹, Zheng G², Ganz R¹, Siebenrock KA¹

¹ Department Of Orthopaedic Surgery, Inselspital, University Of Bern, Switzerland
² MEM Research Center, ISTB, University of Bern, Switzerland

moritz.tannast@insel.ch

Introduction: Developmental dysplasia of the hip (DDH) is one of the most frequent causes of secondary osteoarthritis (OA). The deficient acetabular coverage in dysplastic hips leads to increased contact pressure resulting in an accelerated degeneration of the joint. The goal of contemporary joint-preserving hip surgery is to correct these anatomical abnormalities ideally to decrease the joint loading to a normal level to prevent or at least decelerate the development of secondary OA. The Bernese periacetabular osteotomy (PAO) for the treatment of DDH in adolescents and adults uses four periacetabular osteotomies and a controlled fracture to completely mobilize the acetabulum from the innominate bone [1] (Figure). It allows extensive potential for acetabular reorientation with three rotational degrees of freedom including medial and lateral displacement of the fragment.

To date, several demographic and clinical predictors for poor outcome of PAO have been defined. However, there are only few reports describing radiographic predictors of outcome in terms of femoral head coverage. This is mainly due to a lack of sophisticated methods for appropriate radiographic interpretation. Recently, software Hip²Norm (University of Bern, Switzerland) was presented as a useful, validated tool for computer-assisted radiographic interpretation of anteroposterior pelvic radiographs including calculation for acetabular coverage in caudo-cranial and antero-posterior direction [2,3,4].

In this computer-assisted evaluation study, we investigated the outcome of the first 75 consecutive PAOs. With the help of Hip²Norm we analyzed over 20 radiographic parameters describing the morphology, coverage and orientation
of the acetabulum and questioned whether any radiographic factor predicts a poor outcome at the 20-year follow-up.

Materials and Methods: We investigated 75 PAOs in 63 patients with a mean age at operation of 29±12 (13-56) years and a male-to-female ratio of 17:57. Twenty-three hips (31%) had a previous acetabular operation and 18 hips (24%) presented with advanced preoperative grades of osteoarthritis. Four patients (5%) were lost to follow-up and one patient (two hips, 3%) died. The remaining 58 patients (68 hips) were followed for a mean of 20.4 years (range, 19 - 23). Radiographic analysis were performed preoperatively, postoperatively, at the and 20-year follow-up on anteroposterior (AP) pelvic radiographs and included parameters to assess Osteoarthrosis (Tönnis grades), acetabular orientation (cross-over sign, posterior-wall sign) and coverage (Lateral-center-edge angle [LCE], acetabular index [AI], extrusion index) as well as detailed values for acetabular coverage in caudo-cranial and antero posterior direction (Figure 1). All values were computed with Hip²Norm, an object-oriented cross-platform program for 3D analysis of hip joint morphology using 2D pelvic radiographs [2,3,4].

Results: Forty-one hips (60%) were preserved at last follow-up. Twenty-six hip joints (38%) required conversion to a total hip arthroplasty and 1 hip (1%) had a hip fusion at a mean survival time of 11.7 ± 5.9 (0.9-19.3) years. In comparison to the preoperative radiographic values, there was a significant increase of the postoperative LCE angle from 6±9 (-24-25)° to 34±12 (10-55)°, the caudo-cranial coverage from 64±15 (12-100)% to 88±16 (63-100)% , the anterior coverage from 15±7 (0-31)% to 18±10 (1-56)% , and the posterior coverage from 35±11 (8-63)% to 45±14 (8-72)%. In contrast, a significantly
decrease was found for the AI from 26±11 (12-50)° to 6±11 (-15-18)°, the extrusion index from 37±12 (7-81)% to 10±10 (-13-37)% , the crossover sign from 36% to 17% and the posterior wall sign from 92% to 70. There were no significant changes in radiographic parameters during the 20-year follow-up except for the OA score in the surviving hips which increased from initial 0.4±0.6 (0-2) to 1.1±1.0 (0-3) at 20 years.

A significantly worse outcome at 20-year was found for a preoperative OA grade ≥ 2 (p<0.001) and a postoperative extrusion index ≥ 20% (p<0.004).

**Discussion:** Besides surgical planning and navigation, computer assisted methods are also useful for surgical evaluation. As an example, Hip²Norm was used in this study to assess negative radiographic predictors of outcome of the Bernese PAO. Two radiographic parameters were found as poor predictors: an advanced preoperative osteoarthrosis grade and an undercorrection of the acetabular coverage with a postoperative extrusion index > 20%. This study could show how the evaluation of standard surgical procedures with computer-assisted methods can lead to a change of surgical technique. The proposed method can analogously be used for evaluation of other techniques involving joint preserving hip surgery (e.g. surgical hip dislocation) or for epidemiological purposes.

**References**


Introduction: The aim of corrective osteotomies on deformed lower extremities is the realignment of joint axes and angles in order to transfer the joint load into physiological ranges. State of the art for defining correction parameters for such interventions is either based on statistical geometric values of the human anatomy or on the outcome of follow-up studies. The latter, for example, has led to the conclusion that in cases of high tibial osteotomies (HTO), an over-correction is leading to improved intervention results in comparison to corrections based on statistical geometric parameters [1]. Such findings show that the optimal definition of correction parameters depends not only on the bone geometry itself, but should also include the patient kinematics together with soft-tissue information. To date, the consideration of these rather functional parameters for the intervention plan are purely qualitative and so the success of corrective osteotomies strongly depends on the experience of the surgeon [2]. Biomechanical simulation tools are capable of investigating functional parameters of human musculoskeletal systems (e.g. based on inverse dynamic analysis). Since they are often used in combination with motion analysis, these tools are limited to laboratory environment in which only generic or hypothetical biomechanical models can be simulated.

The aim of this approach is to integrate a biomechanical simulation tool into an existing planning and navigation system for single- and double-cut oblique osteotomies (SCOO and DCOO). By this, the surgeon is getting the possibility to simulate the influence of multidimensional corrective osteotomies on the
entire musculoskeletal system (e.g. joint forces, muscle length changes) and to adapt the correction parameters if necessary.

**Materials and Methods:** In order to enable an individualized intraoperative biomechanical simulation, a 3D human reference model is used which includes a dynamic equilibration simulation (“at ease” standing position). This reference model is scaled and its geometry as well as its posture is adapted based on the results of the intraoperative deformity assessment (segments, joints, muscles etc.). The result is an individual preoperative biomechanical model of the patient. As the system allows the optimal calculation of SCOO or DCOO, the surgeon has the possibility to define the correction parameters in order to simulate an optimal correction of the deformed bone [3]. Similar to the method for preoperative biomechanical model generation, the result of the simulated geometric correction is transformed into a predicted postoperative biomechanical model. The final step is the inverse dynamic analysis of the pre- and postoperative models. This analysis allows a simulated outcome prediction on the influence of the geometric change on joint reaction forces, as well as muscle-tendon length changes of the entire musculoskeletal system of the patient. Once the surgeon is satisfied with the simulated outcome, the system allows the navigated correction osteotomy [3].

In the frame of an in-vitro feasibility study, the deformity assessments of three deformed artificial lower extremities on the basis of calibrated fluoroscopic images, as well as passive kinematic analyses have been performed. After optimal SCO0 simulations near the knee, pre- and postoperative inverse dynamic analyses have been conducted in order to simulate the surgical outcome. The aim of the follow-up ex-vivo study was the feasibility and workflow evaluation of the developed intraoperative deformity assessment in addition to an evaluation of the method for individualized biomechanical model generation. Therefore, five full-body formalin fixed cadaveric specimens have been used.

**Results:** In the case of the in-vitro study, all three femora underwent rotational corrections and their anteversion angles were brought into physiological ranges. Qualitatively, in cases of angular corrections, the geometric changes were associated with the stretching of musculotendinous structures on the concave and the slackening of the structures on the convex side. As all simulated osteotomy procedures (near the knee joint) successfully realigned the mechanical axes of the lower extremities, a force translation in the direction pointing from the knee joint center towards the mechanical axis of the leg was observed. In the case of the ex-vivo study, in all cases an individualized preoperative
biomechanical model could be successfully generated. The time needed for the geometry determination, the biomechanical model generation, and the inverse dynamic analysis was 16 ± 2 minutes (N=30).

Discussion: The novel approach for intraoperative determination of correction parameters for corrective osteotomies on the basis of biomechanical outcome simulation showed feasible results in an acceptable range of time. In the future, the information generated by this approach could also be used to define key data for an individually adapted postoperative rehabilitation (especially muscle length changes). Subject of ongoing work is the evaluation of the influences of simplifications and assumptions necessary for the implementation of this approach.

Acknowledgement: This work has been funded in part by the German Ministry for Education and Research (BMBF) in the framework of the OrthoMIT project under grant No. BMBF 01EQ0402 / BMBF 01IBE02C.

References
Leg Length Discrepancy In Total Hip Replacement: Stem And Cup Navigated Technique Versus Conventional

MANZOTTI A, CONFALONIERI N, MOTAVALLI K, MONTIRONI F

1st Orthop Dept, Cto Hospital, Milan, Italy
alf.manzotti@libero.it

Introduction: The Authors performed a matched paired study between 2 groups: computer assisted THR (Ca-THR) versus conventional freehand techniques for primary hip arthritis using the same implant. They hypothesized that Ca-THR permits a real better control on leg length discrepancy with significant fewer cases of unacceptable levels of disparity. Furthermore they compared the 2 groups according to hip function and number of post operative dislocation.

Materials and Methods: 38 patients with primary hip arthritis who underwent to a Ca-THR from February 2003 to September 2006 were included in the study (group A). At a 6 months follow-up every single patients in group A was matched with a patient who had undergone to a conventional freehand THR (group B) between August 2002 and May 2006 in our hospital. Criteria of matching were age, sex, arthritis grade, BMI and pre-operative limb length discrepancy. Pre and postoperatively limb discrepancy was assessed radiologically using the method of Woolson et al.. The clinical outcome was evaluated using the Harris Hip Score and any dislocation was registered.

Results: There were no significant differences in pre-operative limb length discrepancy between the 2 groups. The surgical time was statistically longer in group A. Post-operatively in group A the mean discrepancy was reduced to 0.6cm with no cases of discrepancy greater of 1cm. In group B the mean discrepancy was reduced to 1.1cm but with 3 (7.8%) cases of discrepancy equal or greater of 1.5cm.

At the latest follow-up no there were no statistically differences in the Harris Hip Score but with an higher score in group A. In group B one patient experienced multiple hip dislocations and was scheduled for a THR revision. No case of dislocation was registered in group A.
Discussion: According to authors experience, despite a longer surgical time, navigation of both stem and cup navigation in THR permits a further significant better control of limb length discrepancy. In the computer assisted group they did not registered any dislocation. The Authors believe navigation in total hip replacement as a valuable tool to lower complications and improve implant performances.

References
Computer-Assisted Intraoperative Measurement Of Leg-Length In Total Hip Arthroplasty: An Accurate And Simple Method

ECKER TM1, STEPPACHER SD1, HAIMERL M2, MURPHY SB1

1 Center Of Computer Assisted And Reconstructive Surgery, New England Baptist Hospital, Tufts University School Of Medicine, Boston, USA
2 Brainlab AG Orthopedic Solution, Heimstetten, Germany

Introduction: Besides epidemiological, implant or surgical approach related factors, a good to excellent result after total hip arthroplasty (THA) depends on technical aspects; particularly correct acetabular and femoral component positioning. Correct postoperative leg length restoration is among the most important goals of hip arthroplasty. Leg length inequality could be associated with hip and back pain, gait disorders, prosthetic impingement with the risk of dislocation, increased polyethylene wear, and could result in early revision surgery [2,4]. Several techniques are commonly used to measure leg length intraoperatively. Most of these techniques are based on identification and comparison of fixed points on the pelvis and the femur before hip dislocation and after implantation of the prosthesis using mechanical jigs or tape measuring. Other methods include comparing the dimensions of the resected bone with the dimensions replaced by the prosthesis or visual comparison of points on non-calibrated pre- and intra-/postoperative radiographs. These techniques have not been reliable because they depend on accurate and reproducible femur repositioning [2,4]. For example, a femur malpositioning in 10° adduction and 10° extension would lead to an apparent error of 13.8mm in leg length [4]. To address the problem of reproducible femur repositioning, several computer-assisted methods were introduced [4,5]. However, these methods showed remarkable disadvantages. They have the need to calculate the hip joint center, which is difficult or often impossible in these mostly destroyed joints and they have the need to establish a femoral coordinate system which is time-consuming. Therefore, we developed, validated and clinically applied a novel
software algorithm based on surgical navigation, which allows the surgeon to restore a defined femur position without establishing a femoral coordinate system or the hip joint center and measure the leg length accurately and simply [1,3].

Materials and Methods: This new leg length algorithm was used in 154 hips (145 patients) that underwent CT-based computer-assisted THA (VectorVision Build 274 prototype; BrainLAB AG, Helmstetten, Germany) with a tissue preserving superior capsulotomy. There were 85 right and 69 left hips, the male-to-female ratio was 85:69 and the mean age at operation was 57 ± 12.8 years (range, 19 - 85 years). Intraoperatively, a pelvic and a femoral dynamic reference bases (DRB) were applied and the anterior pelvic plane (APP) was set as the pelvic coordinate system. Then, the hip joint was put in a neutral position and this position, and the relative position of the femoral DRB relative to the pelvic DRB, was captured and stored by the navigation system. After implantation of the prosthesis the same above described femoral position with the same amplitude of flexion/extension, abduction/adduction and rotation was restored. Now, any resulting difference was due to linear changes (Figure 1, left). Validation of this new algorithm was performed by comparing the navigated results to measurements from calibrated antero-posterior pre- and postoperative radiographs. To adjust the postoperative x-ray for magnification the known cup diameter was used. To calibrate the preoperative x-ray, the interteardrop distance of the preoperative radiograph was compared to the one on the calibrated postoperative x-ray. To minimize the influence of pelvic tilt on leg length measurement, the difference in leg length between the operated and the non-operated side were computed (Figure 1, right). To calculate the radiographic leg length change the preoperative difference was compared to the postoperative difference. The radiographic results were compared to the mean leg length change measured with the navigation system (average of 3 single leg length measurements). Figure 1 Left: The femur is tracked in the pelvic coordinate system which allows for exact repositioning and accurate leg length change measurement. Right: The validation of this algorithm was done on calibrated antero-posterior pelvic radiographs; the change in leg length between the pre- and postoperative status were compared to the results of the navigation system.

Results: No significant difference was found between radiographic leg length change and the results from the navigation system (p=0.658). The mean preoperative leg length difference was -4.7 ± 5.8 mm (range, -30 -11 mm), the postoperative difference was 1.3 ± 4.9 mm (range, -20 - 15 mm) and the
resulting mean radiographic leg length change was 6.0 ± 4.4 mm (range, -5 - 20 mm). The mean leg length change measured with the navigation system was 6.5 ± 4.3 mm (range, -2 - 22 mm). The mean difference between the radiographic results and the results from the navigation system was -0.5 ± 1.8 mm (range, -5 - 4 mm). The mean registration accuracy of the navigation system was 2.04 ± 0.58 mm (range, 0.70 - 3.00 mm).

Discussion: This novel tool has the potential to increase the accuracy and consistency of leg-length change measurement during hip arthroplasty. Improved methods of measuring leg length change during surgery are even more critical now, when smaller incisions are being used, because traditional mechanical measurement methods are potentially even more unreliable than they are when larger exposures are used. This current method of measuring leg length change eliminates the need to calculate the center of rotation of the arthritic hip joint, which is often not accurately possible, and eliminates the need to establish a femoral coordinate system, which can be time consuming and frustrating. Besides registration accuracy, validation with plain radiographs is another potential source of error. Nonetheless, there was a substantial agreement between the radiographic results and the results from the navigation system. This novel computer-assisted method represents an accurate and simple tool for intraoperative leg length measurement.

References
Pinless Array Fixation In Determining Leg Length In Imageless Navigation

PERUMAL V, SWANK ML

Cincinnati Orthopedic Research Institute, Cincinnati, OH, USA
drvenkat_perumal@yahoo.co.in

Introduction: Assess the reliability of a distal pinless array system to determine limb length during total hip arthroplasty using computer assisted navigation.

Literature on limb length after total hip arthroplasty shows 82% have limb length inequality. Most of the surgeons perceive that it is important to address the method of intra-operative equalization of the leg length in THA. A variety of navigation system have been utilized to assess leg length but most require pins in the distal aspect of femur. Concerns related to pin placement including tissue damage, femoral fracture and loss of fixation in osteoporotic bone, make it desirable to use a method which can avoid the morbidity associated with pin placement. We evaluated the first 30 cases we performed with a distal pinless array to assess the limb length during total hip arthroplasty using computer-assisted navigation.

Materials and Methods: A prospective study, IRB approved single surgeon series was conducted with 30 consecutive primary total hip arthroplasty patients using a pin-less distal femoral array. Brain lab 5.0 software was used for navigation using anterior pelvic reference with two pins in the pelvis. A pin less array was applied over the lateral aspect of distal femur and ioban was used to secure the array over the skin. Two drill holes were created in the greater trochanter for the pre operative reference of the limb length before dislocating the hip. The same reference points were registered after components placement and reduction of the prosthetic hip and computer generated limb length calculation was obtained. An independent radiologist measured the post operative limb length with the standard digitized x-ray after calibration. An independent statistician then performed a Bland Altman analysis to determine the level of significance between the intraoperative measurement and the postoperative digital radiograph.
Results: Clinically the patients had excellent restoration of limb length according to the preoperative plan and there was no statistically significant difference between the average of the intraoperative limb length and the postoperative radiograph. However, intraoperative values averaged 2.0 mm higher than the postoperative measurement with two standard deviation limits from -9.6 mm to 13.5 mm. The correlation between methods was 0.254 and was not statistically significant from zero ($p=0.176$). The mean difference of 2.0 mm was not statistically significant using a paired t-test ($p=0.072$). The analysis demonstrates the intraoperative measurements using pinless array, while leading to a reliable adjustment to achieving limb length after THR still have several outliers which weakened the correlation between the methods. In the case where there was a significant discrepancy between the radiograph and the computer, we feel was related to loss of fixation of the pinless array where it was attached to the patients thigh.

Discussion: While pinless array appears promising for limb length measurement in total hip arthroplasty, concerns about adequate fixation of the array to the patients thigh exist and may cause a discrepancy between the limb as measured intraoperatively compared to the postoperative radiograph.
Introduction: There are many reports proving the accuracy of CT based navigation systems. However these systems impose a high dose of radiation exposure to the patients. It is regarded that a CT scan with thinner slices leads to more accurate results, but it causes more radiation exposure. Therefore we compared the accuracy of this system using 1mm slice thickness with 3mm slice.

Materials and Methods: We used the Hip navigation system from Stryker Navigation (version 1.0 update 2). For this study, we used the data from patients who underwent a navigated THA between October 2004 and December 2007. 38 joint replacements (36 cases: 34 cases are females and 2 males, 35 osteoarthritis caused by developmental acetabular dysplasia and 3 osteonecrosis of femoral head) were performed using 3mm slice CT scan, and 20 joint replacements (9 cases all cases are females and osteoarthritis caused by developmental acetabular dysplasia) using 1mm slice CT scan. We recorded the inclination and anteversion of the cup, leg length compared with the opposite side which is showed by navigation intra-operatively. Postoperative CT was taken and deviation of each angle and leg length between navigation and postoperative CT were recorded. We used Trident acetabular cups (Stryker) and CentPillar anatomical stems (Stryker). Mann-Whitney U test was used to analyze each group.

Results: Mean deviation of cup inclination between navigation and postoperative CT is 3.20(0~12) using 3mm slice and 2.87(1~8) using 1mm slice. Mean deviation
of cup anteversion between navigation and postoperative CT is 3.77(0–9) using 3mm slice and 2.65(1–7) using 1mm slice. Mean deviation of leg length compared with the opposite side between navigation and postoperative CT is 2.22(0–9) using 3mm slice and 1.98(1–6) using 1mm slice. Deviation of cup anteversion is smaller by using 1mm slice thickness significantly. But deviation of cup inclination and leg length shows no significant difference between using 3mm slice and 1mm slice.

**Discussion:** It is said that CT based navigation is the most accurate system for total hip arthroplasty, and it is very useful for severe deformity of Japanese osteoarthritis caused by developmental acetabular dysplasia. Moreover many authors indicated about the risk of radiation exposure. However few of them mentioned about how much dose of radiation are exposed. Now in our hospital we are using the CT -Toshiba Aquilion 64 - and we can easily estimate the dose of radiation of our scanning protocol which goes from the top of the pelvis to about 10cm under the knee joint. Mean radiation dose of one time examination is about 2400mGy for 1mm slice and about 1300mGy for 3mm. For information, in our hospital ordinal radiation dose of plain brain CT (10mm slice thickness) is about 1500mGy and abdominal CT (10mm slice thickness) is about 800mGy.

Of course navigated surgeries using 1mm slice thickness are more accurate than using 3mm slice, and the engineers from Stryker or Brain LAB recommend to take 1mm sliced CT. On the other hands it seems sufficiently accurate with 3mm slice thickness from a clinical point of view. Sugano et al. indicated that 3mm slice thickness and 1mm reconstruction pitch may be the optimal trade-off. There are many opinions about the risk of exposure of radiation, and also many opinions about the accuracy of the navigation system, but we should compare the merit and demerit of CT slice thickness for using CT based navigation system.

**References**


Ultrasound Based Localization Of Pelvic Anatomical Coordinate System

FOROUGHI P, SONG DY, TAYLOR RH, FICHTINGER G

1 Department Of Computer Science, Johns Hopkins University, Baltimore, USA
2 Department Of Radiation Oncology, Johns Hopkins University, Baltimore, USA
3 School Of Computing, Queen’s University, Kingston, Canada

pezhman@cs.jhu.edu

Introduction: In Total Hip Replacement, correct alignment of the acetabular component requires precise localization of the pelvic anatomical coordinate system [1, 2]. Typically, computed tomography and fluoroscopy have been used, in conjunction with implanted fiducials and invasive probing of bony landmarks. In this work, we propose an ultrasound based approach that exploits prior knowledge about the anatomy of the pelvis in the form of a surface atlas. Ultrasound is a safe, effective, and affordable intra-operative imaging tool in abdominal surgery. By potentially obviating the need for CT, fluoroscopy, implanted fiducials and invasive probing, it fits well with recent trends in joint arthroplasty. Thousands of images can be acquired in a matter of seconds, with little intrusion to the operating theater. Unfortunately, interpretation and localization of bony structures in ultrasound has been rather subjective, time consuming, and prone to error. These problems demand advanced computational approaches.

We collect tracked ultrasound images from the pelvis, extract surface points, and register them to a statistical atlas in which an anatomical coordinate system had been located by the surgeon. In essence, we map the canonical coordinate system to the given patient.

Materials and Methods: First, we acquire tracked ultrasound images of pelvis, from the left and right iliac crest containing the anterior superior iliac spines and the body of the pubis containing pubic tubercles. These regions are selected based on the definition of the pelvic coordinate system described in [2]. The bone surface is segmented from ultrasound using our method introduced earlier.
The resulting line segments are randomly sampled in the 3D space, to extract evenly distributed sample points from the surface of the pelvis. The collected sample points are used to instantiate a pelvic surface from an atlas previously constructed from CT scans of healthy patients, capturing a mean shape and primary modes of variation [4]. The shape of the pelvis is sufficiently estimated from the weights of the first 15 modes. The weights are calculated using a mode matching scheme similar to that of [5]. The sample points are initially registered to the mean shape using iterative closest point method setting all the mode weights to zero. The mode weights are optimized in an iterative process which minimizes the distance of each surface point to the closest point to the current instance of the atlas. A canonical pelvic coordinate system is defined on the atlas, which matches the patient’s pelvic coordinate system when the pelvic model is fully reconstructed and the registration parameters are found.

**Results:** We first evaluated our method in simulation, to take advantage of solid ground truth and easily controllable model and noise parameters. An instance of the atlas was created, and the surface of the model was sampled at the areas of interest. A randomly generated uniform noise of maximum 2 mm was then added to the three coordinates of each sample. Then a small random transformation was applied to the points with maximum rotation parameters of 5 degrees and maximum translation parameters of 5 mm. Our method was then used to reconstruct the pelvis and find the pelvic coordinate system. This experiment was repeated 100 times, yielding sub-mm and sub-degree accuracies reported in Table 1.

We also conducted two cadaver experiments in realistic intra-operative scenario. We used a low-cost portable SonoSite ultrasound unit and Polaris optical tracking system (Northern digital Inc.) to collect approximately 500 tracked ultrasound images from the cadaver. Without moving the body, we also acquired a full pelvic CT scan with 1.5mm slice thickness. We registered the CT to the atlas as ground truth using [4] and registered the ultrasound to the atlas with our method. We compared the poses of two coordinate systems in Table 1.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Error of anatomical coordinate system localization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>α (degrees)</td>
</tr>
<tr>
<td>Simulation</td>
<td>0.39</td>
</tr>
<tr>
<td>Cadaver 1</td>
<td>0.72</td>
</tr>
<tr>
<td>Cadaver 2</td>
<td>1.36</td>
</tr>
</tbody>
</table>
Discussion: Our ultrasound based system localized the pelvic anatomical coordinate system with a clinically acceptable accuracy of 0.9 degree and 1.7 mm. As a precursor of our work, Chen et al. matched bone surface points in US to a statistical pelvis model with an accuracy of 3.7 mm [6]. Our improvements over Chen’s results are attributed to statistical spreading of the US points, robust initialization of the optimization, and accurate bone segmentation. Ultrasound localization eliminates pre-operative CT, fiducials, and invasive probing. This approach seems applicable in procedures where atlas is readily available. The atlas is an effective source of prior knowledge about the anatomical structure of the bone. It helps compensate for missing data where the acquisition of ultrasound images is problematic due to physical access. Finally, defining the coordinate system on the atlas allows for direct derivation of patient specific frame of reference from the results of registration.

References

Automatic Determination Of Anterior Pelvic Plane For Navigated THA Using 3-d Freehand Ultrasound

Hirschmann MT¹, Helfrich C¹, Schwägli T², Overhoff HM³, Friederich NF¹

¹ Orthopaedic Department, Kantonsspital Bruderholz, Basel, Switzerland
² Smith & Nephew Orthopaedics AG, Aarau, Switzerland
³ Department Of Physical Engineering, University Of Applied Sciences, Gelsenkirchen, Germany

Michael_Hirschmann@web.de

Introduction: In navigation of total hip arthroplasty (THA) the anterior pelvic plane (APP) is widely used as a reference for cup orientation. Generally it is determined by percutaneous palpation of the left and right iliac anterior superior spine and the pubic symphysis. Particularly in obese patients this procedure can lead to APP malorientation due to the thickness of soft tissue between skin and bone [1]. Recent studies have shown that using a tracked ultrasound probe the orientation of the APP could be assessed more precisely [2,3]. In this prospective study we used a system, which allows a fully automatic determination of the APP based on acquired ultrasound data. The purpose of our study was to compare our ultrasound based data of the orientation of the APP with data conventionally assessed by epidigitization of the landmarks. In addition, a possible correlation of APP malorientation with the patient’s BMI and the intraoperative handling of freehand 3-D ultrasound was investigated.

Materials and Methods: In 2007 we examined 25 patients with primary coxarthrosis before implantation of a total hip prosthesis. An ultrasound imaging system with a 5-10 MHz linear probe (EchoBlaster 128, Teledem, Lithuania) was used together with an infra-red optical localizer system (CamBar, Axios3D Services GmbH, Germany) and a Graphical User Interface (PiGalileo, Smith & Nephew Orthopaedics AG, Switzerland) in order to realize a freehand 3-D ultrasound system.

The investigator first determined the pelvic orientation by epidigitization of the landmarks. During freehand 3-D ultrasound acquisition the system guided the user to record a sweep of 50 images in 8 defined regions around the pelvic
landmarks with an appropriate pose of the probe. Discrete ultrasound parameter were preset for focus depth, power, gain and TGC together with a real time image analysis facilitates ultrasound parameter settings. This could help users inexperienced in ultrasound imaging to record the desired structures under good imaging conditions.

The automatic determination of the APP was based on an on-line image segmentation algorithm, which used heuristics on bone representation in sonograms. It led to a voxel cloud showing the delineation of the bone’s surface in the landmark regions. Then a model-based procedure was used to match a 3-D pelvic model with corresponding local landmark geometry into the voxel cloud. The orientation of the APP was defined by the 3-D model and the result could be inspected and confirmed by the operator in a GUI. In a previous cadaver study the accuracy of the described method was determined to be within ±3° for the resulting cup orientation (inclination, anteversion) [4].

Using this setup we compared the palpated plane in relation to the plane found by the ultrasound based procedure regarding APP orientation and resulting cup angles. In addition, we verified the automatic determined landmarks by manually segmenting the ultrasound images and placing the landmarks in the resulting voxel cloud.

**Results:** The median image acquisition time under intraoperative conditions was 12 minutes (range 7-20 minutes). In 23 out of 25 patients complete and plausible data sets could be recorded using navigated ultrasound. The main difference between palpated and automatically determined ultrasound APP was in pelvic tilt, resp. rotation around the transversal axis [Quartile Q1, Q2 (median), Q3: 6.5°, 9.0°, 11.0°]. For the rotation around the longitudinal axis [-1.2°, 1.5°, 2.0°], as well as around the sagittal axis [0.0°, 0.4°, 0.9°] minor deviations were found. The resulting difference for the cup orientation angles resulting from the error in pelvic tilt were for anteversion [4.6°, 6.3°, 7.8°] and for inclination [-0.4°, 2.8°, 3.4°]. It turned out that differences >10° in pelvic tilt tended to be more likely in patients with BMI>26, but it was not possible to find a correlation for estimating difference in pelvic tilt from patient BMI.

Fig 1: Difference in resulting cup orientation (inclination, anteversion); Difference in pelvic tilt in relation to patient BMI.

The APP calculated by the automatic procedure was found to be accurate and robust compared to the APP determined by manual image segmentation and landmark placement in the ultrasound data. Absolute differences for resulting
cup angles were in an acceptable range for inclination [0.2°, 1.0°, 1.5°] and anteversion [0.9°, 1.5°, 2°]. The calculation time for the automatic algorithm was less than one minute for each dataset.

**Discussion:** Ultrasound supported navigation in THA is a promising technology which could eliminate systematic errors in orientation of the APP in relation to conventional navigation using percutaneous palpation of landmarks, especially for obese patients. The GUI guidance with automatic on-line image segmentation and simplified ultrasound parameter setting simplified the acquisition of good images, but there are still improvements in acquisition workflow and user guidance needed to lower the learning curve. The APP found by the automatic 3-D ultrasound procedures showed an accurate and reliable landmark determination. To validate the accuracy of the method a study is ongoing to compare the intraoperative determined APP by freehand 3-D ultrasound with post-op CT-scan.

**References**


Incidence Of Dislocation After Computer-Assisted Positioning Of The Acetabular Cup For Total Hip Arthroplasty Based On Joint Kinematics

BHATTACHARYYA M, GERBER B

Department Of Orthopedic, University Hospital Lewisham, London, UK

mayukhbhattacharyya@hotmail.com

Introduction: Acetabular component orientation during total hip arthroplasty affects dislocation; hip arthroplasty navigation systems have been introduced to avoid the errors reported after acetabular component orientation using a manual technique [1]. Orthopilot navigation systems for computer-assisted total hip arthroplasty (THA) may be used to address component malposition. This system, however require acquisition of multiple bone landmarks on the pelvis to define the frontal pelvic plane.

The purpose of this study was to analyze our preliminary results to report the incidence of dislocation encountered in the clinical practice.

Materials and Methods: 38 primary THA were implanted with the orthopilot system (26 women, 12 men, mean age 68 +/- 7.8 years, age range 54-83 years) for degenerative hip disease. One optoelectronic rigid body was fixed percutaneously on the pelvis after cutaneous palpation for bony landmarks. The acetabulum was prepared first followed by the femur using reamers and broaches of increasing size. The acetabular cup was positioned only with the navigation system in the pilot cases.

Results: An average inclination of 42.0 degrees (range: 38 degrees -50 degrees; SD+/-2.8 degrees) and an average anteversion of 14.4 degrees (range: 5 degrees -25 degrees; SS+/-5.0 degrees) were obtained in the computer-assisted study group. One patient fell three weeks after implantation causing posterior dislocation; there was recurrence and revised. Another had a hematoma and dislocation was reduced on 4th post-operative day, when the patient was fully
mobilized. The third patient had a dislocation on the 2nd post-operative day at the time mobilization.

**Discussion:** This method can be used in routine without lengthening operative time significantly and helps position the cup. This study demonstrated that there is no ideal position for the cup, which can be used for all patients. Dislocation may occur with computer assisted cup position.

The study cases were inside the safety zone recommended by Lewinnek. Computer assisted navigation of the acetabular cup in THR requires reliable digitalisation of bony landmarks defining the frontal pelvic plane by user driven palpation. According to the system recommendations the subcutaneous fat should be held aside during epicutaneous digitalization. To improve intraoperative practicability this is often neglected in the symphysis area. In these cases the fat is just compressed and not pushed aside [2]. In this study soft tissue thickness may have led to quantify potential misinterpretation of cup anteversion triggered by the simplified palpation, although the reference we employed that had been acquired by recommended palpation.

The accuracy of placing the acetabular component within a predefined safe zone using computer guidance was achieved with respect to the anterior pelvic plane. Factors other than acetabular component orientation may also contributed to the incidence of dislocation [1]. However, we believe that inaccurate landmark registration and simplified palpation was a potential source of error. Uneven soft tissue distribution can influence navigation inaccuracy. Further research is necessary in the Navigation of the acetabular cup in total hip replacement (THR) to improve the reproducibility of acetabular component positioning. As epicutaneous palpation of anatomic landmarks is necessary to determine the pelvic coordinate system, soft tissue distribution may affect anteversion accuracy of the palpation procedure in orthopilot acetabular cup navigation. Moreover, the variation of the anterior pelvic plane, which guide computer-assisted navigation, from supine to the standing position would produce a significant variation in the orientation of the anterior plane of the pelvis. This may also be a source of error, which may leads to dislocation when patients become ambulatory. This should be integrated into the imageless navigation systems.
References


Current Accuracy Of Anterior Pelvic Plane Registration In Supine Position

THORNBERY RL1, NELSON LS2

1 Florida State University, Tallahassee, FL, USA
2 Georgia State University, Atlanta, GA, USA

hthorny2@aol.com

Introduction: Computer navigation systems have been found to increase the accuracy of component positioning for total hip arthroplasty. Most navigation systems use the anterior pelvic plane (APP) as a reference plane in calculating the different component positions. The benefit of using a computer navigation system largely relies on an accurate registration process. The purpose of this study is to examine the variability of accurately defining the anterior pelvic plane by current techniques.

Materials and Methods: Anterior pelvic plane registration variability was measured and examined using three male cadavers (average age = 86 years, average height = 66.6 in, average weight = 148.3 lbs). The APP was calculated by identifying the bilateral anterior superior iliac spines (ASIS) and bilateral pubic tubercle (PT) landmarks. A modified version of the BrainLAB VectorVision hip software (BrainLAB AG, Munich, Germany) was used to calculate anteversion and inclination angles of the APP. A reference array was affixed to the pelvis in a similar manner and position to the standard computer assisted total hip arthroplasty procedures. Six observers (orthopedic surgeon, physician assistant, research assistant and three clinical consultants) performed ten consecutive registrations of identifying all APP landmarks with the soft tissue intact on each cadaver in the supine position before changing to the next cadaver. Then, an experienced surgeon (RLT) dissected and inserted screws flush into the bone at the site of the pubic tubercle landmarks to correctly and repeatably identify these landmarks when registering the APP. The six observers each performed five consecutive registrations of the APP with the PT landmarks exposed and identified. After registering the APP with the PT landmarks exposed, the surgeon dissected and inserted screws flush in both ASIS landmarks to accurately identify all landmarks of the APP plane. All
observers performed three consecutive registrations on each cadaver with all landmarks exposed and identified. Mean anteversion and inclination angles were calculated with the ASIS and PT landmarks exposed and identified for each specific cadaver. These mean anteversion and inclination angles were used as the reference angles to compare the angles of the other two experiments with the soft tissue intact and with the PT exposed and identified. The data was normalized by calculating the angle differences between the standard angles and the angles with the soft tissue intact. Additionally, angle differences were calculated between the reference angles and the angles with the PT landmarks identified. The angle differences of the two experiments were used to examine APP registration variability.

**Results:** Table 1 shows the average anteversion and inclination angle differences when registering the APP with soft tissue intact and registering with the exposed and easily identifiable pubic tubercle landmarks. A significant difference in anteversion angles were found between registering the APP with the two methods examined in the study (p<0.05). However, no significant differences were found between the inclination angles of the APP (p<0.05).

<table>
<thead>
<tr>
<th>Anteversion angle with pubic tubercle screws</th>
<th>N</th>
<th>Range</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Stdev</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclination angle with pubic tubercle screws</td>
<td>90</td>
<td>6</td>
<td>-3</td>
<td>3</td>
<td>-.06</td>
<td>1.344</td>
<td>1.806</td>
</tr>
<tr>
<td>Anteversion angle with soft tissue intact</td>
<td>180</td>
<td>15</td>
<td>-3</td>
<td>12</td>
<td>5.17</td>
<td>3.230</td>
<td>10.434</td>
</tr>
<tr>
<td>Inclination angle with soft tissue intact</td>
<td>180</td>
<td>6</td>
<td>-2</td>
<td>4</td>
<td>.17</td>
<td>.962</td>
<td>.925</td>
</tr>
</tbody>
</table>

**Discussion:** The current study examined the variability of accurately defining the anterior pelvic plane. Computer navigation systems use the APP to calculate component orientations during total hip arthroplasty (THA). Wolf et al. have shown that correctly identifying and registering the APP landmarks is vitally important to reducing error in orientating the components during THA and a small error in the registration process can significantly effect the final component orientation. When identifying the APP with soft tissue intact, the standard deviation of the anteversion angle is almost 2.5 times greater than that found when registering the APP with the pubic tubercles exposed and identified with screws. Our large variation in anteversion angles when registering the APP versus the variation in inclination angles coincide with the findings in a
similar study by Spencer et al. Our subject population consisted of thin male specimens, which eliminated the negative effects of additional soft tissue that can potentially lead to greater inaccuracies when registering the APP.

Any computer navigation system developed that does not use the APP as a reference for calculating component orientation needs to be at least or more accurate than the results reported using the APP.

References


Imageless Navigation-Assisted Implantation Of Acetabular Components In Revision Total Hip Arthroplasty

CHANG JD, YOO JH, UMARANI GS, LEE JH

Department Of Orthopaedic Surgery, Hangang Sacred Heart Hospital, Hallym University College Of Medicine, Seoul, Korea

jdchangos@yahoo.com

Introduction: Cup position plays an important role in the short- and long-term outcomes of total hip arthroplasty (THA). Malposition of the cup, in a short-term, is a direct cause of dislocation, and leads to an impingement of acetabular cup. In a long-term, it affects wear and breakage of the liner and stability of the cup.

More attention should be paid to avoid malposition of acetabular components during revision THA, which is the most common cause of dislocation. Considering the increasing demand for an exact cup position, the use of computer-assisted orthopaedic surgery (CAOS) is getting more attention. Purpose of this study was to evaluate the accuracy of imageless navigation for the placement of acetabular components during revision THA.

Materials and Methods: A prospective randomized clinical study was performed with a total of 40 acetabular components. They were divided into two groups during revision THA: imageless navigation group (VectorVision, Brainlab, Munich, Germany, n = 20) and freehand technique group (n = 20).

Demographic data of the two groups was not different in the aspects of mean age (53.9 ± 12.4 vs. 51.6 ± 12.7 years), gender (M/F; 11/8 vs. 12/7), site (left/right; 8/11 vs. 10/9), body weight (60.5 ± 7.8 kg vs. 62.7 ± 9.4 kg), body mass index (21.7 vs. 22.9), the interval from primary to revision THA (10.7 ± 3.4 yrs vs. 11.7 ± 4.3 yrs), and preoperative diagnoses for primary THA, etc. All of the retrieved acetabular components were cementless cups. Femoral stems
were revised in 11 hips in navigation group and 12 hips in freehand technique group.

The operation was performed through a posterolateral approach with the patient lateral by single surgeon. The anterior pelvic plane was determined by percutaneous palpation of the anterior superior iliac spines and the pubic symphysis and was registered with the computer. Acetabular bone morphing was performed after removal of acetabular component. During the reaming procedure, inclination and anteversion angles were measured. After calibration of the cup impactor, insertion of the acetabular component was navigated. Once the cup was inserted in the acetabulum, the anteversion and inclination angles were verified and estimated. All of the inserted components were cementless cups. The inclination and anteversion of acetabular components were compared between two groups using imageless navigation and freehand technique on the postoperative radiographs.

**Results:** Inclination was 40.5° (range, 19.9°-62.6°; SD 9.7°) in freehand group and 44.5° (range, 41.8°-48.3°; SD 2.0°) in navigation group (P = 0.067). Anteversion was 15.8° (range, 1.8°-25.8°; SD 6.4°) in freehand group and 19.4°(range, 12.3°-23.0°; SD, 2.9°) in navigation group (P = 0.069).

However, the number of outliers in inclination and anteversion were 3 (15%) and 4 (20%) in freehand group, respectively, while it was 0 in navigation group. One dislocation (postoperative 4 days) and one medial wall protrusion occurred in free hand group. No other complications were observed in either group.

**Discussion:** Imageless navigation is a reliable technical tool, which reduces the variation and inaccuracies of conventional freehand placement of the acetabular component in revision THA. Further studies with more cases are required to confirm above results and to evaluate the improved mid- and long-term survival of the implant in arthroplasty of the hip.
Cost-Utility-Analysis Of A Novel System For Computer-Aided Revision Total Hip Arthroplasty

ELFRING R¹, ZIMOLONG A², QUACK E², HOPPE T², DE LA FUENTE M¹, RADERMACHER K³

¹ Helmholtz-Institute For Biomedical Engineering, RWTH Aachen University, Germany And Synagon Gmbh, Aachen, Germany
² Synagon Gmbh, Aachen, Germany
³ Helmholtz-Institute For Biomedical Engineering, RWTH Aachen University, Germany

elfring@hia.rwth-aachen.de

Introduction: The number of Total Hip Revisions will rise by 137 % until 2030 [1]. Surgical techniques as well as the support by novel technology are necessary to achieve an optimal medical outcome for the patient and to keep the costs at a minimal level at the same time. The Helmholtz-Institut of the RWTH Aachen University together with partners developed components for gentle removal of cemented hip prostheses. A prospective cost-utility-analysis has been performed by Synagon comparing this new approach with the conventional procedure.

Materials and Methods: A comparative prospective Cost-Utility-Analysis (CUA) was performed measuring all costs in monetary units (Euros) and the benefits or utilities in natural units. The analysis focused on differences between the new and the conventional approach, which was used as reference.

Four groups of stakeholders affected by the intervention were included in the analysis: the patient, the provider (i.e. the hospital), the health care provider, and “others”. A wide range of parameters taken from literature and studies performed by the developers was classified by relevance to the different stakeholders and evaluated.

The outcome for the patient was measured in so called QALYs (Quality Adjusted Life Year). Inspired by the work of Dong and Buxton [3], a Markov-Model with eight states was set up and implemented, simulating the different state of health of a patient over the time from the first RTHR surgery until death (Figure 1). In
each simulation step, the patient is provided with a QALY value, specific for his current state of health. After this, the succeeding state is determined evaluating the transition probabilities given. These differ between the conventional and the new intervention. It was decided to discount the QALYs with 3% per year. The QALY value for each state was estimated based on [4]. For conventional surgery, transition probabilities were determined from literature. For the new approach, transition probabilities were estimated based on similar interventions known from literature. The transition probabilities into death were adjusted such that the mean life span meets the statistical rest of life (with an additional risk of death during the surgery according to [2]). A sensitivity analysis was performed to account for uncertainty in the transition probabilities.

Two types of cost-indicators were analyzed in detail: The costs of the surgery itself and the costs of length of stay. For the conventional intervention, the sequence of actions and the used resources were recorded in form of Event-driven Process Chains (EPC). Based on these paths, the path for the new procedure was predicted and the differences in time consumption as well as in resource usage were identified. For the conventional intervention, the average costs for different cost categories are given by the InEK [2]. The average duration of a conventional intervention is also known. From these facts and the estimation of time and resource savings, the cost difference between the average conventional surgery and the new approach could be calculated. A similar way was chosen to determine the costs of length of stay.

Thanks to the Zero-Dose preview of the new system, the number of actually taken images can be significantly reduced, resulting in a reduction of radiation dose. Since no reliable model for the calculation of QALYs from radiation dose is available, the change in radiation dose itself can not be taken as assessment factor.

**Results:** Differences between the two systems result from four major influences: the use of a navigation system, the use of the Zero-Dose-System, the navigated cement removal, and the minimal invasive approach. The Markov-Model was run for 10,000 patients for the conventional and for the new surgical technique. The amount of QALYs earned by the average patient increased from 6.89 to 7.13. By reducing the average number of fluoroscopic images from 20 to seven, the radiation exposure is expected to decrease by 64%. The costs of the surgery itself were altered mainly by saving operation time. The additional time needed for the navigation system is more than compensated by the savings made by the Zero-Dose preview and in particular by the cement removal. The Zero-Dose-System saves up to 90% of the images taken and hereby an average of 12 minutes. The cement removal can be done in 20 minutes (46 minutes
conventional). A total of 21 minutes can be saved in an average surgery which leads to a saving of 205€ per intervention including some additional materials needed for navigation (like tracking markers).

A reduction of the length of stay from 16.7 days (from InEK) by two days is expected due to lower soft tissue damage and optimized clinical pathways, saving the hospital as much as 324€ per intervention.

Discussion: The analysis shows that the system increases quality of life for the patient as well as it reduces costs during intervention and postoperative care. However, due to high investment costs per system, this is only profitable for specialized centers with a large number of cases. Furthermore, the results are only applicable for a specific patient group: only a part of the prostheses are cemented and in some cases the cement removal is fast and easy so that the system would not be used at all.

It was decided that it is not reasonable to calculate one single value incorporating all results, but to leave the results of the different benchmark dimensions.

ACKNOWLEDGMENT This work has been funded in parts by the German Ministry for Education and Research (BMBF) in the framework of the OrthoMIT project under grants No. 01EQ0402 and 01EQ0421.

References


[4] Laupacis, A.; Boune, R.; Rorabeck, C.; Feeny, D. The Effect of Elective Total Hip Replacement on Health-Related Quality of Life, JBJS(Am), 75 (1993), 1619-1625
**Pelvic Tilt Before And After Total Hip Arthoplasty**

**KLINGENSTEIN G¹, ECKMAN K², JARAMAZ B¹, MURPHY SB¹**

¹ Center For Computer Assisted And Reconstructive Surgery, New England Baptist Hospital, Boston, Massachusetts, USA
² The Robotics Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
³ Institute For Computer-assisted Orthopaedic Surgery, The Western Pennsylvania Hospital, Pittsburgh, Pennsylvania, USA

skidoc@gmail.com

**Introduction:** While surgical navigation offers the opportunity to accurately place an acetabular component, questions remain as to the optimal goal for acetabular component positioning in individual patients. Overall orientation of the spino-pelvic structures may be the single greatest variable affecting the desired goal for acetabular component orientation(1). The current study assesses supine and standing pelvic tilt, before and after hip replacement.

**Materials and Methods:** 39 consecutive patients undergoing primary total hip arthroplasty were studied prospectively. There were 22 men and 17 women, with an average age of 59.8 years (range 17 to 80). Supine and standing radiographs of the pelvis and a CT study for CT-based surgical navigation were obtained prior to surgery. Post-operatively, a supine radiograph was obtained 6 weeks following surgery and a standing radiograph was obtained 12 weeks following surgery. 2D-3D matching of each radiograph to the 3D CT dataset was performed using X-align, a previously validated software algorithm(2,3). This software is able to identify pelvic rotation, with respect to the anterior pelvic plane, to within one degree. Pelvic tilt supine and standing, before and after surgery, could then be calculated.

**Results:** Preoperatively, the mean supine pelvic tilt was 3.12 degrees +/- 6.97° (range -12.9 to 17.3) and the mean standing pelvic tilt was -1.62° +/- 6.99° (range -14.7° to 18.1°). After total hip replacement the mean supine pelvic tilt was 2.92° +/- 7.76° (range -12.2° to 17.0°) and the mean standing pelvic tilt
was -3.16° +/- 7.06° (range -18.9° to 14°). The difference in supine pelvic tilt before and after surgery was not statistically significant. However, the variation between standing preoperative and postoperative flexion of -1.53° was statistically significant. The mean difference in supine to standing pelvic tilt was greater preoperatively (5.0° more tilt supine) than postoperatively (2.84° more tilt supine).

**Discussion:** Measurements from the current study document that pelvic tilt is highly variable between individual patients. Patients generally have more pelvic tilt in a supine than in a standing position. After total hip arthroplasty, supine pelvic tilt does not change significantly compared to preoperatively and the change in pelvic tilt between the supine and standing positions is less. This may be due to the fact that spino-pelvic motion must be greater pre-operatively due to restricted hip motion and that the lumbar spine may be under less stress when more normal hip motion is restored post-operatively. Those patients with significant negative pelvic tilt may be better served with acetabular component orientation that has less anteversion and flexion than the orientation that would be used for patients with normal pelvic tilt. Further studies of pelvic tilt in various positions before and after surgery may help to define more objective goals for acetabular component positioning in individual patients.

**References**

The Equidistant Method: A Novel, Robust And Accurate Strategy For Computer Simulated Femoroacetabular Impingement Detection

PULS M, STEPPACHER SD, SIEBENROCK KA, TANNAST M, KOWAL J

1 MEM Research Center, ISTB, University of Bern, Switzerland
2 Department Of Orthopaedic Surgery, Inselspital, University Of Bern, Switzerland
3 Center For Computer Assisted And Reconstructive Surgery, New England Baptist Hospital, Tufts University, Boston MA, USA

marc.puls@memcenter.unibe.ch

Introduction: Although in general considered as a ball and socket type of joint, the hip does not perfectly rotate around one fixed rotation center. This subtle irregularity is based on the conchoid shape of the normal femoral head [1] or on the pathomorphologies related to femoroacetabular impingement (FAI), which is known as a major factor in developing early osteoarthritis [2]. As a consequence in computer-assisted surgery, the virtual motion of a native hip joint is hard to simulate without creating non-realistic impingements by violating the natural joint gap. In the past, different hip joint simulations were developed and evaluated regarding their ability to reproduce patient specific hip motion patterns, mainly applied to determine the hip range motion in the fields of gait analysis, navigation and planning for total hip arthroplasty. However, only very few of these strategies were used for diagnosis of FAI. We developed and validated a novel hip joint simulation strategy for detection and quantification of FAI. It was hypothesized that this strategy is superior regarding accuracy and robustness compared to established strategies described in literature.

Materials and Methods: An experimental, in-vitro accuracy study was performed, evaluating 50 different prepared plastic hip joint models and two human cadaveric hip specimens. The following four methods for hip motion simulation were compared (Figure 1). (1) A simple method which is characterized by a predefined fixed rotation center determined by an existing
pivoting algorithm [3]. (2) A constrained method, which also uses a fixed rotation center, but includes only impingement points within a 5 mm distance to the acetabular rim [4]. (3) The translated strategy virtual moves the femoral head away perpendicular to the computed collision area once an impingement is detected [5]. (4) The equidistant method tries to preserve a constant joint space by superposing the acetabular and femoral sphere centers based on the individual joint anatomy. For evaluation, the real impingement recorded by a navigation system (Marvin, MEM Research Center, Switzerland) was compared to the virtual collision detection based on the four strategies. Five plastic pelves and ten corresponding femurs (Synbone AG, Switzerland) were used for evaluation, resulting in a total of 50 different joint configurations. Each bone was remodelled with radio-opaque epoxy to simulate different normal and pathological morphologies (cam, pincer type, and combined types of FAI [2]). To compensate for the lack of cartilage, the plastic acetabula were prepared with felt pads. 3D-models from the plastic bones were generated by using a tracked hand-held laser scanner (Steinbichler Optotechnik GmbH, Traunstein, Germany). For the cadaver tests, the hip specimens were dissected with the acetabular/femoral cartilage and the labrum left intact. A computer tomography of the specimens was performed and 3D-models were obtained by using the Amira Visualization Software (Mercury Computer Systems Inc., Chelmsford, MA, USA). During the tests the fixed rotation centers were determined by an established pivoting algorithm. Two orthopaedic surgeons performed clinically relevant motion patterns to detect anterior FAI. The identified impingement areas were digitized with a tracked pointer under optical control. The tests with the cadaver specimens were repeated five times for each side. The recorded motion paths were then applied to each strategy and compared to reality.

**Results:** The equidistant method was the strategy with the highest and the simple strategy with the lowest validity, respectively (Table 1).

<table>
<thead>
<tr>
<th>Methods</th>
<th>Sensitivity [%]</th>
<th>Specificity [%]</th>
<th>PPV [%]</th>
<th>NPV [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>72.7 (65.6)</td>
<td>54.5 (0.3)</td>
<td>17.2 (6.6)</td>
<td>93.9 (8.8)</td>
</tr>
<tr>
<td>Constrained</td>
<td>68.6 (67.3)</td>
<td>41.3 (0.3)</td>
<td>17.5 (7.2)</td>
<td>87.8 (8.6)</td>
</tr>
<tr>
<td>Translated</td>
<td>73.4 (86.7)</td>
<td>74.8 (33.2)</td>
<td>28.2 (12.8)</td>
<td>95.4 (95.7)</td>
</tr>
<tr>
<td>Equidistant</td>
<td>86.1 (85.6)</td>
<td>87.9 (88.2)</td>
<td>48.1 (45.9)</td>
<td>98.0 (98.1)</td>
</tr>
</tbody>
</table>

Table 1. Summary of the validation results for detection of FAI (numbers in brackets represent the values of the cadaver tests).

At the time of real impingement, the equidistant method had a significantly smaller mean distance between the actual impingement point and the femur and
a smaller femoral angular deviation to the real impingement point (p < 0.001, Table 2).

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean distance [mm]</th>
<th>Additional angle [degrees]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>$1.7 \pm 1.2 \ (1.8 \pm 1.2)$</td>
<td>$3.6 \pm 3.0 \ (3.7 \pm 3.4)$</td>
</tr>
<tr>
<td>Constrained</td>
<td>$1.7 \pm 1.2 \ (1.8 \pm 1.2)$</td>
<td>$3.6 \pm 3.0 \ (3.9 \pm 3.6)$</td>
</tr>
<tr>
<td>Translated</td>
<td>$1.7 \pm 1.0 \ (1.1 \pm 0.8)$</td>
<td>$3.4 \pm 2.4 \ (2.4 \pm 2.6)$</td>
</tr>
<tr>
<td>Equidistant</td>
<td>$1.0 \pm 0.7 \ (1.0 \pm 0.7)$</td>
<td>$2.0 \pm 1.8 \ (2.0 \pm 2.3)$</td>
</tr>
</tbody>
</table>

Table 2. Mean distances and angular deviations between real impingement and femoral 3D model (number in brackets represent the values of the cadaver tests).

**Discussion:** The equidistant method represents the most robust and accurate strategy in detecting anterior FAI in comparison to the other, known strategies. Unlike some of these [3][4], it can even be used in hips where no concentric joint space can be found any more. To prove its practical usefulness, the validity of the equidistant method has to be performed in an analogous in-vivo study. Nevertheless, this strategy has the potential to simulate more complex motion patterns for even larger hip deformities, e.g. hips with dysplasia or Leg-Calvé-Perthes disease. It serves as a useful tool for more accurate three-dimensional analysis of hips with FAI and as the basis for potential minimally-invasive treatment of these pathomorphologies.

Figure 1: Schematic illustration of the four compared hip motion strategies: (1) simple, (2) constrained, (3) translated and (4) equidistant strategy.

**References**

A Haptic Device For Robot-Aided Milling Of Curved Bone Surfaces For Implants

HUNGR NA1, HODGSON AJ1, PLASKOS C2

1 The University Of British Columbia, Vancouver, Canada
2 PRAXIM, La Tronche, France

nahungr@interchange.ubc.ca

Introduction: A generally accepted goal in orthopaedic surgery today is to maximize conservation of tissue and reduce tissue damage as long as this does not otherwise compromise the functional outcome of the surgery [1][2]. An example of this is the conservation of bone during implant placement. The vast majority of implants, however, have bone-mating surfaces based on standard geometric shapes. More complex resurfacing shapes that reproduce the natural curvature of bone structures have been considered too complicated to sculpt using standard bone saws. In fact, no simple, small, reliable, inexpensive and universal bone sculpting technique currently exists that would justify the practical utilization of such surfaces.

Various bone sculpting systems have been developed both for research and clinical purposes and can be classified as either active, passive, or semi-active. Active robots, such as Robodoc, act autonomously and eliminate human precision errors, but their autonomous actions carry safety risks which many surgeons are unwilling to accept. Passive robots, such as Praxiteles and Brigit, autonomously place a passive cutting guide in pre-calculated positions, but leave the cutting itself to the surgeon. At present, they are limited to planar cutting surfaces. Semi-active robots, such as Acrobot and the Mako Haptic Guidance System, use haptic techniques that rely on motor impedance to provide motion constraints and are intended to be more flexible than passive robots while still having the surgeon perform the cutting. Such techniques have been reported to have limited stiffness, making it difficult to realistically emulate hard contact even when using large and expensive direct-drive motors with sufficient torque capability [3][4]. These systems are typically large and free-standing, and hence take up significant space in the operating room. Other semi-active...
systems, such as PADyC and COBOTs, use direct mechanical constraints to create realistic-feeling hard surfaces, but they have not yet been successfully applied to bone shaping.

These advantages and drawbacks were used to form a list of design objectives for an ideal distal femoral bone sculpting device:
- Semi-active design.
- Unrestricted freedom of motion when not in contact with the virtual surface.
- High precision and rigidity.
- Smooth surface following.
- Minimum obstruction.

**Materials and Methods:** The distal femoral bone sculpting device presented here is based on a new haptic hard-surface emulation concept in which the mechanisms that generate the active constraints are mechanically decoupled from those that provide the passive guidance. This concept is illustrated in figure 1a, and relies on the assumption that all distal femoral bone-sculpting surfaces are approximately convex and centred near the epicondylar axis. The surgeon manipulates a milling tool attached to the end of a 2DOF manipulator. When the surgeon attempts to penetrate the pre-specified bone resection boundary, the radial dimension locks up to prevent incursion. The radius \( r \) at which locking occurs is a function of \( \theta \).

A response inherent to this concept is that a lateral deflection along the surface is caused when the user applies a force against the physical constraining element which produces a moment about the attachment point. This can be seen in Figure 1a by imagining a user pushing vertically down on the tool tip at the rightmost position of the linear surface. Since the radius would be physically limited at the point of incursion, the arm would rotate clockwise. This would cause a change in \( \theta \), which would signal the robot to increase the minimum radial distance permitted, which in turn would tend to push the user to the right. This effect grows in strength the closer the direction of the applied force is to the perpendicular of the radial distance \( r \). A typical femoral bone sculpting application, however, whose surfaces are close to convex, will be minimally affected. Even in more extreme cases, we felt that this effect would be easily learned and anticipated by human operators and easily avoided. To verify this and to test the overall concept, we built a prototype for testing. The prototype is shown in Figure 1b and is based on Praxim’s Praxiteles mini-robot architecture, described in [5]. Praxiteles’ rotational milling guide was replaced by an unpowered link that is free to move about the second axis. A
driven rotational physical constraint is used to constrain the angle to which the free link can be moved. The position of this constraint is adjusted automatically based on the angular position of the first unpowered and unconstrained axis.

**Results:** Results from preliminary tests with a number of subjects and using the prototype to emulate planar, elliptical and Biomet Repicci-type surfaces are very promising. The effect of a hard virtual surface is emulated very successfully. The stiffness of the system is truly realistic with a satisfying “click” at the moment of contact increasing the effect of a hard constraint. When not in contact with the virtual surface, motion appears frictionless. Surface tracing is also virtually frictionless, smooth and satisfactory. The lateral deflection effect, described above, is noticeable if the tangent of the surface approaches the radial line distance between the end-effector and the device’s attachment point. At the far side of a horizontal line, for example, the device can produce a noticeable lateral deflection, especially if the surface is approached quickly. We found, however, that with an understanding of the device’s operation and careful handling, this effect can be easily accommodated. With curved implant-like shapes, the effect is virtually unnoticeable.
**Discussion:** This novel haptic concept seems to be a feasible and potentially very advantageous method for the development of a miniature bone mounted distal femoral bone-sculpting device.

**References**

2. Engh GA. Orthopedics. 2007; 30(Suppl 8): 55-7
The Acrobot Sculptor® Robotic System
For Hands-On Orthopaedic Surgery

JAKOPEC M1, HEDE BP1, HARRIS SJ1, BARRETT ARW1, RODRIGUEZ Y BAENA FM2,
GOMES MPSF1, DAVIES BL2, COBB JP2

1 The Acrobot Company Limited, London, UK
2 Imperial College London, London, UK

matjaz.jakopec@acrobot.co.uk

This paper presents a new robotic system for hands-on orthopaedic surgery, the Acrobot Sculptor® System. The device is based on the Active Constraints concept, invented by the Imperial College London research group, which was clinically tested with an initial prototype on TKR patients in 2001 [Computer Aided Surgery, 2001, Vol 6 No. 6, pp. 329-339], and, in 2003/2004, went through a regulated, prospective, randomised, double-blind (patient and evaluator), controlled versus conventional UKR surgery study (J Bone Joint Surg [Br] 2006;88-B: 188-97).

The Acrobot Sculptor® system has been substantially redesigned and addresses the shortcomings of the initial prototypes. This compact system is comprised of a Sculptor Arm and a digitising arm, which are mounted on a trolley together with a touch-screen monitor (see FIG).

The Sculptor Arm is a small, low powered 3-axis robot, with a high speed rotary cutter mounted onto the arm via a passive remote centre mechanism (RCM, patent pending). The Sculptor arm constrains the position of the ball-ended tip of the cutter to a pre-defined safe region of any shape, whilst the design of the RCM allows the orientation of the cutter (and hence the approach) to be freely chosen by the surgeon.

The digitising arm allows dynamic tracking of the patient’s position throughout the procedure, and hence removes the need for rigidly clamping the bone. The digitising arm enables the Sculptor Arm constraints to be updated in real time. The Acrobot Sculptor® can be integrated with any open-platform navigation solution.
The surgeon holds onto the cutter and guides the Sculptor Arm in free mode to register the bone or, under active constraints, to machine the surface of the bone. In this way, the surgeon is totally in control of the operation, whilst the system provides high accuracy of bone preparation. The simple and intuitive touchscreen Graphical User Interface (GUI) is controlled directly by the surgeon, and provides colour-coded feedback of the quality of the produced surface.

The system will be used clinically on UKR patients in the first half of 2008. Early clinical experience will be presented at the conference.
A Hybrid Manipulator Mechanism Design For A Small Bone Attached Surgical Robot

S O N G S, J A R A M A Z B

I c a o s: I n s t i t u t e F o r C o m p u t e r A s s i s t e d O r t h o p a e d i c S u r g e r y, T h e W e s t e r n P e n n s y l v a n i a H o s p i t a l, P i t t s b u r g h, P A, U S A

s s o n g @ i c a o s . o r g

I n t r o d u c t i o n : E a r l y g e n e r a t i o n a c t i v e s u r g i c a l r o b o t s i n o r t h o p a e d i c s a r e u s u a l l y l a r g e a n d h e a v y s t a n d - a l o n e t y p e s u c h a s R O B O D O C a n d C A S P A R. T h e a t t e m p t t o b r i n g a d v a n t a g e s o f r o b o t t e c h n o l o g y i n t o s u r g e r y o f t e n r e s u l t e d i n s i m p l y b r i n g i n g a m o d i f i e d i n d u s t r i a l r o b o t i n t o o p e r a t i n g r o o m. R e c e n t l y, s m a l l b o n e m o u n t e d r o b o t s h a v e b e e n i n t r o d u c e d i n o r d e r t o o v e r c o m e v a r i o u s d i s a d v a n t a g e s o f l a r g e a n d h e a v y s t a n d - a l o n e t y p e s u r g i c a l r o b o t s. I t s e e m s t h a t a s p e c i f i c a l l y d e s i g n e d s m a l l r o b o t t h a t i s a t t a c h e d o n t o i t s t a r g e t h a s b e e n s u c c e s s f u l s o l u t i o n f o r t a r g e t i m m o b i l i z a t i o n, w h i c h i s m a j o r i s s u e i n r o b o t i c s u r g e r y [1, 2, 3].

O n e s u c h r o b o t i s a m i n i b o n e a t t a c h e d r o b o t i c s y s t e m ( M B A R S ) [4] d e v e l o p e d f o r P a t e l l o - F e m o r a l j o i n t r e p l a c e m e n t ( P F R ) s u r g e r y. T h e h e x a p o d r o b o t d e m o n s t r a t e d s a t i s f i e n g p e r f o r m a n c e f o r t h e g i v e n t a s k. H o w e v e r, i t a l s o h a d s o m e d i s a d v a n t a g e s, e s p e c i a l l y f o r s u r g i c a l u s e.

I n o r d e r t o a v o i d s u c h p r o b l e m s a n d t o o p t i m i z e t h e r o b o t i c s u r g e r y, a n e w k i n e m a t i c c o n f i g u r a t i o n w a s d e s i g n e d b y o b s e r v i n g a d v a n t a g e s a n d d i s a d v a n t a g e s o f t h e e a r l y s t a n d - a l o n e t y p e a n d t h e r e c e n t b o n e a t t a c h e d r o b o t s. A p r o t o t y p e b u i l t f r o m t h e n e w r o b o t c o n f i g u r a t i o n i s i n t r o d u c e d w i t h f u r t h e r d e s i g n o p t i m i z a t i o n d i r e c t i o n s f o r p r a c t i c a l i m p l e m e n t a t i o n.

M a t e r i a l s a n d M e t h o d s : W i t h r e s p e c t t o k i n e m a t i c c o n f i g u r a t i o n, m a n i p u l a t o r s c a n b e d i v i d e d i n t o s e r i a l o r p a r a l l e l. T h i s w o u l d b e a f u n d a m e n t a l r o b o t d e s i g n c o n s i d e r a t i o n f o r a n y g i v e n t a s k a n d c o n d i t i o n. I n g e n e r a l, s e r i a l m a n i p u l a t o r s h a v e l a r g e r w o r k s p a c e w i t h r e s p e c t t o t h e i r o w n v o l u m e a n d g r a n d e d b a s e s p a c e. H o w e v e r, b e c a u s e o f i t s l o w s t r u c t u r a l s t i f f n e s s a n d a c c u m u l a t e d j o i n t e r r o r s, l a r g e m o t o r s a n d o r / h i g h g e a r r a t i o t r a n s m i s s i o n s a r e o f t e n u s e d w i t h
strong link body typically resulting in a large and heavy robot. Parallel manipulators, on the other hand, have higher structural stiffness as more links are connected to the end effector. This multiple linkage structure also averages link errors so that higher accuracy can be achieved. However, typical parallel manipulators have limited workspace due to their mechanical joint limits and collision of links.

Based on the features of serial and parallel manipulators, it is noticed that the early generation surgical robots have typical serial manipulator problems and yet their designated task area is very isolated despite the large available workspace. In other words, serial configuration may not be the correct choice for the surgical tasks. Contrary to that, the hexapod type bone attached robot offers typical advantages of parallel manipulator in terms of weight and structural rigidity. However, it also has disadvantages of parallel structure such as limited workspace, relatively large grounded base and complexity of the six degree-of-freedom (DoF) robot.

Results: From outlined observations, it was determined that serial structure is less suitable for surgical robots that aim to be light enough to attach onto bone and maintain rigidity against significant external forces (i.e. reaction forces from high speed bone cutting). Besides, known disadvantages of parallel structure are mainly based on a typical hexapod robot. Hence, new parallel structures, that have benefits of closed-chain linkage and can avoid disadvantages of typical hexapod, were sought.

In general (not for oscillating saw cutting), high-speed bone surfacing involves mainly XY planar cutting with relatively shallow depth direction cutting throughout. Based on that, two simple kinematic concept models were designed shown as Figure (a) and (b). (a) is a 3 DoF serial manipulator that consists of three hinged translational joints (passive rotational joints driven by translational manipulation) creating XYZ workspace. Whereas, a hybrid model (b) has two hinged translational joints creating XY planar movement, which is serially linked from vertical Z axis.

Since structural rigidity is mainly expected along the XY plane, and to simplify inverse kinematic computation i.e. XY and Z motion can be decoupled and controlled separately for faster response, the hybrid model (b) was selected for a new kinematic configuration.

For the translational joints, zero-backlash lead-screw and belt pulley transmission was selected to build all three axial mechanisms. A double hinged end effector holder was designed to fasten a surgical tool. Also, a new bone mounting structure was designed to provide a secure robot base with minimal (or no) extra incision for the robotic installation. The mounting structure and the
robot are fastened with a ball joint, which allows an initial manual position. The robot and the mounting structure were manufactured from stainless steel and it weighs approximately 1.3kg including a Stryker TPS surgical drill and three motors. Figure (c) shows the robot mounted on distal femur.

Discussion: The new robot design development was focused on manipulator mechanism optimization for enhanced structural rigidity, weight reduction and greater workspace usage under the given surgical task and condition of PFR. Although the robot can be simply bagged for sterilization purpose, further mechanical design optimization - maintaining benefits of the new kinematic design - may be required for easier sterilization. As one of possible design solutions, an embedded telescope-like robot design is proposed for a future development. Mechanical parts such as powertrain and transmission can be placed inside of a sealed extendable cylindrical robot arm so that the robot can deliver the same manipulation. Also, the cylindrical arm should provide greater rigidity against bending and buckling.
References


Full Automatic Reduction Of Femoral Shaft Fractures Using A Surgical Robot

OSZWALD M\textsuperscript{1}, WESTPHAL R\textsuperscript{2}, CITAK M\textsuperscript{1}, KENDOFF D\textsuperscript{1}, HÜFNER T\textsuperscript{1}, WAHL FM\textsuperscript{2}, KRETTKE C\textsuperscript{1}, GOSLING T\textsuperscript{1}

\textsuperscript{1} Department Of Trauma Surgery, Hannover Medical School, Hannover, Germany
\textsuperscript{2} Institute For Robotics And Process Control, Technical University Of Braunschweig, Braunschweig, Germany

m.oszwald@web.de

Introduction: Robot assisted reduction of femoral shaft fractures has been described in several experimental publications of different workgroups. The described setups of these “master-slave” applications can only be defined as manipulators. In our earlier studies we also integrated the robot as a manipulator. These were i.a. precursor tests for the full automatic reduction (see figure below). Aim of this study was to develop a full automatic application to perform a realistic reduction of a femoral shaft fracture, autonomously from the surgeon.

Materials and Methods: To establish a full automatic system, we divided up the complex algorithm of fracture reduction into defined subsections. These subsections had to be technically realized and implemented. The activities of the system had to be visualized transparently at any point of time during the reduction procedure. As a template for the software programming we regarded the surgeon’s actions during his reduction maneuver. The surgeon first analyzes the fracture, related to the him available imaging. Second, according to this imaging of the fracture-site, he generates an ideal image of the reduced fracture in his mind. Third, considering the localization of the main fragments, the surgeon will develop a strategy and pathway to perform the reduction. Fourth, the actual manipulation of the fragments will take place. Here the surgeon must rely on his tactile and visual information (e.g. fluoroscopic x-ray imaging). He will monitor the whole process until the final reduction result has been reached. The robotic system we developed had to solve all tasks of these subsections. We examined the feasibility in a single embalmed cadaveric human specimen with an artificially applied femoral shaft fracture.
Results: To obtain a transparent reduction procedure, we decided to implement intraoperative 3D imaging. We used an isocentric fluoroscope to generate a 3D dataset of the fracture site. This dataset was transferred to the robot controlling PC. Here a virtual 3D surface model was reconstructed with near-real-time actualization to offer an intuitive transparent visualization tool.

The uprising forces and torques of the adjacent soft-tissue and by fragment collision were measured by a 6-DOF force-torque sensor and displayed numerically and graphically. The ideal image of the reduction result was calculated by a specially developed and validated matching-algorithm, using iterative methods to reconstruct the original femur out the fragments (published separately). Localization of the two main fragments was provided by an optical navigation system. The matching algorithm could then calculate the parameters of dislocation of the two main fragments from each other. These parameters of dislocation defined the end-point position for the reduction pathway. Visual information was based upon the tracking information of the navigation system. Tactile information was based upon the measurements of the 6-DOF force-torque sensor.

The reduction procedure then was devided into several primitives of action: manipulation within the coordinate system, complying with the shortest reduction pathway and minimization of the uprising forces. The primitives of action were arranged in a hierarchy and updated within milliseconds. With this method, reacting of the surgeon on changing conditions during the reduction procedure was simulated. The feasibility of the system could successfully be shown in our experiment in the cadaveric human specimen.
Discussion: We could develop a complex system for full automatic fracture reduction of femoral shaft fractures. This system can run completely autonomous from the surgeon. At all times monitoring or even intervention of the surgeon are possible during the whole procedure of fracture reduction. In the next step of examinations, accuracy of the system must be evaluated. Advantage of such a system is a high precision of the reduction result combined with a gentle reduction pathway. The system operates independently from the experience of the surgeon.
Experimental Study Of The Bi-Planar Navigation Robot System Aided Screws Visualization And Insertion Of Sacroiliac, Femoral Neck And Distal Locking

WANG JQ¹, HU L², ZHAO CP¹, SU YG¹, LIU WY², WANG Y², WANG TM², WANG MY¹

¹ Department Of Orthopaedics And Traumatology, Jishuitan Hospital, Beijing, China
² Robotics Institute, Beijing University Of Aeronautics And Astronautics, Beijing, China

jnhy12345@163.com

Introduction: To evaluate and investigate the clinical feasibility and curative effects of The Bi-planar Navigation Robot System aided Screws Visualization and Insertion of Sacroiliac, Femoral Neck and Distal locking.

Materials and Methods: The hardware components of the system include a PC computer with a monitor, auto mechanical stereotactical localization cubic frame, localization operative apparatus; special navigation software can be used for registering and real-time tool navigation controlling(Fig.1).

1. Sacroiliac screw: In a simulated surgical setup, 12 AO cannulated screws(diameter, 7.3mm) were placed into the S1 vertebral bodies of 4 human pelvic bone under the bi-planar navigation robot system guidance(Fig.2). To compare this new technology with the conventional technique, 12 cannulated screws were placed into 3 Synbone pelvic models under fluoroscopic control.

2. Femoral Neck: 15 guided pins are inserted into 5 Synbone model bones and we measure the distance difference between random two pins at entry point and out point. Calculate the ratio(P) of the difference to the length of the pin through the Synbone to evaluate how parallel of the two pins(Fig.3). And compare the time of X-ray exposure of robot aided treatment with the 12 normal operations.
3. Distal locking: 20 Synbone tibias (the first distal hole) were inserted with intramedullary nailing, 20 distal locking were performed with the robot system. To compare this new technology with the conventional technique, 20 distal locking screws were placed into the same tibial models (the second distal hole) under fluoroscopic control (Fig. 3).

The fluoroscopic times and the radiation exposure time and operation time between image acquisition and guidewire insertion were recorded.

**Results:** Sacroiliac screw: With the bi-planar navigation robot system guidance, the average fluoroscopic times were 2.5, the average radiation exposure time were 1.5 seconds, the average operation time were 4 minutes and 13 seconds. All the screws are in the safe area. Under fluoroscopic control, the average fluoroscopic times were 20.3, the average radiation exposure time were 13.7 seconds, the average operation time were 4 minutes and 6 seconds. Two screws (16.7%) were misplaced. The fluoroscopic times and the radiation exposure time were reduced significantly when using the bi-planar navigation robot system (P<0.05). For operation time, no significantly difference was found (P>0.05).

2. Femoral Neck: P is about 0.37%〜1.81%, and X-ray exposure time of robot aided system is 2.3s vs 28.37s of normal operations.

3. Distal locking: All distal holes except 1 hole were locked successfully, in 5 of 20 holes (25%), the drill bit touched the canal of the locking hole, albeit with no damage to the nail. The fluoroscopy time per screw was 1.23±0.31 seconds.
**Discussion:** The bi-planar navigation robot system provide precise navigation for insertion of screws. Using this system, the radiation exposure to the patient and the staff can be reduced significantly. The results of this prospective controlled experimental study are encouraging and lead to further clinical trial.

Structural characteristics and mating apparatus

1. Structural characteristics

The system consists of three modules: Image acquiring and processing, surgical path planning, and choice of surgical plan. General structure of the system is shown in figure 1. Four sets of radiopaque steel ball markers and four radiable scales are embedded into four quadrilateral face plates on front, rear, top, bottom sides of the cubic frame respectively. Mobile position holes are fixed on the right and left face plates (located on internal and external side of fractured limb during operation). Space axes of the position marker are conscious. During operation, image workstation register entopic and lateral view images of surgical object obtained by C-arm or mobile X-ray device, and work out precise space axis of surgical object and markers. The computer controls the hole-locating unit to move to the position which image workstation planned by remote operated auto-controller, and reconfirm the position where screw should be driven in and out. The frame is made of nonradiable medical stainless steel and radiable medical high molecular material. A mobile unit is fixed on top of the frame.

2. Technical features are concluded as follow:
   (1). It adopts mechanical arm locating technique and differentiates form other navigating systems. Special devices it required are simple and occupy no more space. So it doesn’t disturb normal layout of operating room. (2). The auto-frame navigation system not only may monitor and track surgical tools on real time but also may assist surgeon during surgery. It simplifies normal freehand operation by located surgical tools and supplies help for surgeon. (3). It combines surgical operations of screw insertion to steps of computer planning. Its operative procedure is simple. Surgeon may understand its working principles and surgical plan easily, and may perform the operations lonely without help of engineer and technician. Its possibility of error operation is few. Its operations are accordance with surgeon’s normal operative habits and are really acceptable.(4). Only two fluoroscopic images obtained by C-arm or X-ray fluoroscopic device are required during surgery. No continuous radiation exposure is needed. Its clinical application decreases X-ray exposure and radiation damage to medical staffs and patient intensively. (5). It locates
with high precision. The software is with friendly interfaces and supply many programs for correcting error to ensure a safe and precise surgery.(6). The system is universal, modular and suitable for three types fracture.

References
A Magnetoelastic Strain Sensor
For Wireless Tibia Fracture Healing
Assessment

OESS NP1, WEISSE B2, NELSON BJ1

1 Institute Of Robotics And Intelligent Systems, ETH Zurich, Switzerland.
2 Laboratory For Mechanical Systems Engineering, EMPA, Switzerland.

noess@ethz.ch

Introduction: Certain types of bone fractures require an internal implantable plate to support the broken bone as it is consolidating. Sometimes, during the bone fracture healing process, complications can arise, resulting in implant failure. Measuring the strain in the plate over time provides information about the bone fracture healing process and thereby allows to avoid implant failure. Strain gauging is the most commonly used technique to measure strain on mechanical components. Applying strain gauging on biomechanical devices for in vivo measurements requires an invasive procedure, since wire leads have to be introduced inside the body of the patient. Magnetoelastic sensing offers a wireless, highly sensitive and low-cost technique of measuring strain in internal plates. This technique makes the use of the change in magnetic permeability with respect to mechanical strain of a passive sensor operating in the radio frequency. The magnetoelastic sensor is made of a magnetostrictive and amorphous alloy. An emitter/receiver unit consisting of magnetic coils, is placed outside the body of the patient. This work proposes a wireless method to measure strain in internal plates based on magnetoelasticity.

Materials and Methods: In the considered model, the human tibial bone is replaced by a generic tibia made of polyurethane foam. The generic bone is cut in two and the two parts are joined together by a plate fixated with screws to the bone. A gap of 21mm is left between the two bone parts. This net cut represents an extreme case of fracture in order to emphasize the behavior of the plate under various loadings. The ribbon shaped and 20mm x 6mm x 25 microm-sized Vitrovac 4613M13 sensor is bonded on the outer surface of the orthopedic plate, next to the fracture. Since magnetoelastic sensors are not biocompatible, this issue is overcome by using a biocompatible glue to bond the ribbon sensor
to the plate and a thick layer of this glue is applied on top of the sensor to cover it. The bone-plate system is tested under compression and tension in static loading conditions. The sensor output response curves are drawn by measuring the peak voltages as a function of applied force. The measurements are repeated five times and the average values of these responses are shown.

**Results:** The strain measurement domain of magnetoelastic sensing is between $10^{-3}$-$10^{-6}$ m/m compared to that of strain gauging, which is between $10^{-2}$-$10^{-5}$ m/m. A finite element analysis was performed to determine whether the strain on the plate is included in the measurement domain of magnetoelastic sensing. When the bone-plate system is subjected to 1000N in extension, the calculated strain on the outer surface of the plate is $-8 \cdot 10^{-4}$ m/m. For a human tibial bone in similar conditions - that is, when the fracture is a 21mm net cut and the applied load is 1000N in extension - the strain on the outer surface of the plate is estimated between $5 \cdot 10^{-6}$-$10^{-5}$ m/m. Consequently, magnetoelastic sensing can be used to measure strain on plates supporting fractured generic and human tibial bones.

When the generic fractured tibia is subjected to a force - in its longitudinal axis - a bending moment is generated at the plate. Thus, the axial strain on the plate results from combined pure axial loading and bending. The calculations obtained from the finite element analysis show that the strain on the plate due to bending is greater than the strain due to pure axial loading. Consequently, when the generic bone is subjected to compressive stress, the outer surface of the plate, and thereby the sensor, is subjected to extensive stress.

The bone-plate system is loaded with a compressive force up to 2000N and then unloaded. The voltage change generated by the magnetic flux density inside the pickup coil increases linearly when the bone-plate system is subjected to compressive loads, whereas the voltage decreases linearly when the loads are removed. The hysteresis of the bone-plate system can be observed after the unloading.

Increasing the intensity of the interrogating magnetic field below the saturation range of the sensor, in turn, increases the amplitude of the sensor’s output amplitude and the slope of the sensor’s linear zone, due to a change in magnetic susceptibility. This can be observed when the system is subjected to compressive stress and the sensor bonded to the plate is pulsed under different magnetic field intensities (9, 38 and 63mOe).

Under incremental compressive loads of 100N, ranging from 0 to 1500N, applied on the bone-plate system, the sensor output response curve shows a high squared linear correlation coefficient $R^2$ of 0.9724. To determine the sensor resolution, incremental compressive loads of 10N, ranging from 0 to 200N, are
applied on the bone-plate system. The resulting 20N and 1.6·10^5 m/m sensor resolution is determined for the Vitrovac 4613M13 magnetoelastic ribbon. The high sensitivity is obtained thanks to the outstanding magnetoelastic properties of the sensor material and the magnetic coils setup designed to improve the signal-to-noise ratio.

**Discussion:** Magnetoelastic sensing has been investigated to measure strain in orthopedic plates for bone fracture healing assessment to avoid implant failure. Besides its wireless nature and its low-cost, this technology displays a high sensitivity, which has been demonstrated in this work through the high linear correlation and the high resolution of the measurement results.

**References**

Computer Aided Navigation In Revision Total Knee Arthroplasty: Does It Make Our Job Easier?

Deep K

Golden Jubilee National Hospital, Glasgow, UK

kamal.deep@gjnh.scot.nhs.uk

Introduction: Revision knee arthroplasty is a well established procedure for a failed primary total knee arthroplasty. Sometimes the revision implants are also used in complex primary situations. There are not many good long term studies on revision knee replacements. Medium to long term results remain rather poor with 3-5 yr satisfactory results ranging from 46% - 84%. Complication rate in these studies has been reported to be 13% - 30%.

Outcome of surgery and its longevity are dependent on various factors. Precision in the alignment of prosthesis, recreation of joint line and adequate soft tissue balance remain paramount. Though there are other factors involved such as infection, amount of bone loss, recreation of the lost bone substance, it is paramount that one gets a stable, well balanced, well aligned, level knee joint constructed at the end of the procedure. Computer navigation can help to a big extent in achieving this.

Materials and Methods: There are not many revision navigation programmes available in the market for clinical use (hardly any proved ones). We used the software for primary total knee replacement and exploited its advantages in using it for revision knee surgery. A Stryker system was used to perform the procedure with Scorpio TS revision instrumentation and prosthesis. A modification of the original recommended technique was necessary to use computer navigation along with the routine instrumentation. Fourteen revision knee replacements were done using the technique.

Results: There was a learning curve and it took four cases to fully streamline the new technique. Innovative steps were introduced to use the software for a primary knee arthroplasty for a revision situation. It worked very well and we were able to achieve the alignment within three degrees of biomechanical axis.
in all the cases. It was especially helpful in sizing the gap produced, sizing 
the augments needed, level of the joint line produced and balancing the soft 
tissues.

**Discussion:** Revision surgery is a difficult procedure and since most of the 
normal anatomy, which is present in primary situations may be lost. Anything 
or any help in this situation is appreciated by the surgeon. Computer navigation 
can be very handy in helping with alignment, sizing the spacers, sizing the 
augments and recreation of joint line. Protocols, specific to revision surgery, 
need to be written up to help with this difficult procedure. Authors present one 
such simple solution even in the existing systems.
Errors In Identification Of The Distal Femur Transepicondylar And Anterior Posterior Axes In Minimal Incision TKR And Conventional Incision TKR Using Image Free Computer Navigation System

YAU WP, LIU KG, YAN CH, CHIU KY

Department Of Orthopaedic Surgery, Queen Mary Hospital, Hong Kong, China

peterwpy@hkucc.hku.hk

Introduction: The objective of this study was to compare the errors in the identification of the Transepicondylar Axis (TEA) and the Anterior Posterior Axis (AP Axis) of the distal femur between a MIS approach and a Conventional-Incision approach using an image free computer navigation system. The errors in aligning the rotation of the femoral prosthesis were compared with the reference Transepicondylar axis established by computerized tomogram. The inter- and intra-observer errors are reported.

Materials and Methods: Four sections of fresh frozen cadaveric lower limbs with intact knee and ankle joint were studied. The joint was first approached using MIS arthrotomy. The length of the incision was approximately 10 cm. A mini quadriceps tendon splitting technique was used. The patella was retracted laterally to expose the joint. TEA was defined as a line joining the two femoral epicondyles. The medial and the lateral femoral epicondyles of the cadaveric knees were identified clinically by palpation. The AP Axis is defined as a line joining the deepest point of the trochea and the highest point of the intercondylar notch of the distal femur. These two landmarks were identified in the cadaveric knees by visual selection. Repeated identification of the TEA and AP Axis was sequentially performed twenty-five times by each of the two orthopaedic surgeons in the same setting. The spatial orientations of these axes
were recorded using an optical computer navigation system (Vector Vision CT Free Knee 1.1, BrainLAB).

Subsequently, the wound was extended to approximately 20 cm and the cadaveric knee was approached in a conventional incision manner. The quadriceps tendon was split proximally until complete eversion of the patella was possible. The tibia was subluxed anteriorly. The two axes were identified twenty-five times sequentially by each of the two orthopaedic surgeons in the same setting once again. The spatial orientations of these lines were stored using the optical computer navigation system.

Computerized tomogram of the entire limb was performed with a 16-detector CT scanner (Lightspeed-16, General Electric, Milwaukee, USA). The medial and lateral femoral epicondyles in the axial CT images were identified by six independent observers (four orthopaedic surgeons and two radiologists) on two separate occasions which were at least one week apart. The average of these data was used to calculate the reference TEA. The errors in the identification of the TEA and the AP Axis in both the MIS approach and conventional incision approach were calculated by comparing the data recorded by using the navigation system with this reference TEA established by CT. The null hypothesis was assumed. It stated that there was no difference in the errors in the identification of the TEA and the AP Axis using computer navigation technique between the MIS approach and the Conventional incision approach using an image free navigation system in a cadaveric knee model. This was examined by independent t test. Statistical significance was assumed if p < 0.05. Potential outliers were defined as an error in the identification of these two axes of more than five degrees. The numbers of outliers in the two approaches were reported.

Results: The mean errors in the identification of the TEA in the MIS approach and conventional incision approach were 4.5º internal rotation (SD 4º), and 3º internal rotation (SD 4º), respectively. The error in identifying the TEA in the MIS approach was significantly higher than the conventional incision approach (p<0.001, independent t test). If a surgical outlier was defined as more than five degrees from the neutral alignment, 46% of the observations in the MIS approach and 37% of the observations in the conventional approach fell into the outlier zone.

Concerning the interobserver difference, more than 50% of the observations made by observer 1 fell into the outlier zone, in contrast with only 28% in the second observer.

The mean error in the identification of the Anterior Posterior Axis of the distal femur across all specimens using the MIS approach was 0º (SD 5º). The mean
error in the identification of the Anterior Posterior Axis of the distal femur across all specimens by using the conventional incision approach was 1.8° internally rotated (SD 5°). If a surgical outlier was defined as more than five degrees from the neutral alignment, 25% of the observations in the MIS approach and 36% of the observations in the conventional approach fell into the outlier zone. Concerning the inter-observer difference, the amount of outliers in observer 1 and observer 2 were 32% and 28% respectively.

Discussion: Concerning the degree of precision in the identification of the Transepicondylar axis, it was found in the current experiment that the adoption of the MIS approach led to a significant increase in both the mean error and the number of outliers of greater than five degrees. In terms of the identification of the Anterior Posterior Axis of the distal femur in the current experiment, it appeared that the precision was not jeopardized by the limited approach employed (MIS approach: 0°, SD 5°; Conventional approach: 1.8°, SD 5°). This was probably because the two landmarks which formed the Anterior Posterior Axis (i.e. the deepest point of the femoral trochea and the highest point of the intercondylar notch) were selected by visual identification and could be seen clearly in both the MIS and conventional incision approach. To conclude, the precision in the identification of the Anterior Posterior Axis of the distal femur was not ostensibly jeopardized by the use of MIS approach in the current experiment, although the range of the error in the identification of this axis was extremely wide. On the other hand, the adoption of the minimal incision approach led to an increase in error in the identification of the Transepicondylar axis. There was a higher percentage of surgical outliers of more than five degrees internally rotated error when the Transepicondylar axis was identified with the minimal incision approach. Significantly higher inter-observer difference was observed in the identification of the Transepicondylar axis of distal femur.
A Navigated 8 In 1 Femoral Cutting Guide For Total Knee Arthroplasty - Development And Accuracy Study

KENDOFF D1, PLASKOS C2, KARKARE N2, GRANCHI C2, MAREAU-GAUDRY A2, SCULCO T1, PEARLE A1

1 Hospital For Special Surgery, New York, USA
2 Praxim Inc, Walpole, MA, USA

kendoffd@hss.edu

Introduction: Long term outcomes of modern total knee arthroplasty have shown good results within the last decades, although intramedullary alignment does affect the implant position in multiple plans. Minor deviations in the insertion point of an IM guide can result in alignment errors of several degrees. Besides adequate identification of the perfect IM mid positions, the IM rod diameter and length used play an important role while another limiting factor of the femoral implant position is the phenomenon of bone cutting errors after the cutting guides were applied to the femur. Recently, 8in1 cutting guides have been introduced, which permit the surgeon to perform five planar cuts plus all three notch cuts using one guide template. Although incorporating cutting planes within a single template helps to maintain the congruency of the bone cuts, positioning such templates in surgery can be illusive. This is due in part to the total amount degrees of freedom (DOF) that must be adjusted simultaneously (6DOF for an 8in1). In order to combine the advantages of mechanical and technical innovations we developed a new 8in1 femoral cutting guide that does not require any primary fixation or IM guides in the bone, and that could be adjusted completely under navigated control. The hypothesis of our study were twofold: 1) navigation allows for precise alignment and adjustment of a new femoral 8 in 1 cutting guide with negligible variance in the initially planned vs achieved implant position. 2) resulting femoral cuts are very accurate without relevant cutting errors.

Materials and Methods: We demonstrate our approach with the Universal Knee Instrument (UKI, Precimed Inc. USA), a versatile 8 in1 TKA guide designed
to perform all femoral cuts with a single jig, as previously described in [1]. We integrated an array of “adjustable constraints” into the UKI by machining four threaded holes directly through the template. Adaptation to a navigation system has been performed by integrating the adjustable constraints protocol on the open platform Surgetics Station (PRAXIM-medivision, France), which uses BoneMorphing technology. Utilizing the combined navigated and mechanical positioning and optimal adjustment of the femoral jig after registration of the bony anatomy includes the following positioning algorithm:

1. Implant planning
2. Position of cutting planes
3. Position of cutting guide
4. Axes of adjustment screws
5. Intersection of axes with bone surface
6. Screw adjustment distance from reference surface
7. Guide tracking + real time updating of screw adjustment distances

Once the surgeon plans the optimal implant size and position intraoperatively based on the mechanical axis, knee balancing in flexion and extension, and Bone Morphing acquisitions, the system indicates the required adjustment length for each screw. The surgeon can preadjust each screw using a screwdriver such that when the template is positioned on the bone, it corresponds to the desired position.

Cadaver testing included ten fresh frozen specimen, from hip to toe. Based on the registration process, a femoral implant size is suggested by the computer. Navigated planning of the femoral component fit included the following parameters:

1. flexion, valgus/varus, and component rotation
2. medio-lateral, proximal-distal, and anterior-posterior positioning

After completed planning, one surgeon (DK) placed the UKI instrument under permanent navigated control on the distal femur. Based on the computers measurements, the required screw pre-adjustment from the guide reference surface was done each of the four screws mechanically, consequently the template could be positioned on the bone, it with its desired position/depth of the screws. The femoral trial implant was impacted and its final position was measured with the navigated pointer on defined registration cones that were machined on the femoral implant. The final implant position was saved in the system, the trial removed and all performed cuts were measured with a defined navigation module. A navigated pointer collected data directly on the following bony cuts: anterior, posterior, distal, chamfer and notch cut. At least 100 points were collected per cut and the best fit planes in a least squares sense were fit to each set of data points, compared to the planned implant plane [2].
Accuracy measurements between planned and achieved positioning and cutting procedures were performed at the following steps:
1. Initial jig placement
1. Jig position after fixation
1. Jig position after cuts
1. Implant trial position
1. Complete cuts after trial removal (final cut accuracy measurements)

**Results:** The error (Mean ± Standard Deviation, SD) in the UKI position before and after fixation, and in the final trial component position is presented in Table 1a. All errors are relative to the planned implant position as planned on the navigation screen. The Error in the Planned Cut Position vs. Actual Cut position as measured by the point probe is presented in Table 1b.

<table>
<thead>
<tr>
<th></th>
<th>Error in UKI position before fixation</th>
<th>Error in UKI position after fixation</th>
<th>Error in final trial component position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varus/Valgus [°]</td>
<td>-0.1±0.7</td>
<td>0.0±0.8</td>
<td>0.9±1.7</td>
</tr>
<tr>
<td>Flexion [°]</td>
<td>-0.3±1.3</td>
<td>-0.3±1.8</td>
<td>2.9±2.5</td>
</tr>
<tr>
<td>Distal Cut Height [mm]</td>
<td>0.0±0.4</td>
<td>0.1±0.3</td>
<td>-0.3±1.0</td>
</tr>
<tr>
<td>Axial Rotation [°]</td>
<td>-0.3±1.1</td>
<td>0.2±1.4</td>
<td>0.8±2.7</td>
</tr>
<tr>
<td>Anterior-Posterior [mm]</td>
<td>0.7±1.4</td>
<td>1.0±1.6</td>
<td>3.4±1.3</td>
</tr>
<tr>
<td>Medial-Lateral [mm]</td>
<td>NA</td>
<td>NA</td>
<td>1.0±2.3</td>
</tr>
</tbody>
</table>

**Table 1 A**

<table>
<thead>
<tr>
<th></th>
<th>Sagittal Plane Error [°]</th>
<th>Coronal/Axial Plane Error [°]</th>
<th>Distance between two planes at centre of cut [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal</td>
<td>1.7±0.8</td>
<td>0.3±1.1</td>
<td>0.6±0.5</td>
</tr>
<tr>
<td>Posterior</td>
<td>-5.1±4.9</td>
<td>-0.4±1.6</td>
<td>2.2±1.4</td>
</tr>
<tr>
<td>Posterior Chamfer</td>
<td>2.5±1.0</td>
<td>-0.7±1.2</td>
<td>0.4±0.1</td>
</tr>
<tr>
<td>Anterior Chamfer</td>
<td>-1.1±1.3</td>
<td>-0.4±2.4</td>
<td>0.9±0.5</td>
</tr>
<tr>
<td>Anterior</td>
<td>-1.4±1.4</td>
<td>-0.8±1.9</td>
<td>1.2±1.3</td>
</tr>
</tbody>
</table>

**Table 1 B**
**Discussion:** Using the Adjustable Constraints positioning method the surgeon was able to bring the guide within ~1mm/° of the desired position in less than about one minute. We observed a larger error in execution of cuts than in the positioning of the guide. This could be due to several factors, including the inherent inaccuracies associated with the sawing process, such as blade flexibility and blade toggle in slot and motion of the cutting block during cutting [3,4]. In particular, errors were highest for the posterior cut, where the guide surface was considerably smaller and narrow (<10mm). A novel ‘CAS-enabled jig’ has been developed and validated. The system allows for direct execution of a complex, multi-planar CAS plan with single navigated device.
Imageless Electromagnetic Or Infrared Navigation In Total Knee Arthroplasty: How To Choose?

CHEUNG KW, CHU KH, LEE KS

Department Of Orthopaedics And Traumatology, Prince Of Wales Hospital, The Chinese University Of Hong Kong, Hong Kong SAR, China

kwcheung@ort.cuhk.edu.hk

Introduction: Imageless navigation in total knee arthroplasty (TKA) has been proven with better alignment than conventional technique. Infrared (IR) imageless navigation is the most commonly used navigation system in TKA currently. Electromagnetic (EM) navigation was introduced in recent few years, which aimed at higher accuracy and less interference of the operating field. There was limited result of electromagnetic navigation in total knee arthroplasty being published.

Materials and Methods: From August, 2006 to December, 2007, 45 patients had TKA performed with electromagnetic navigation (EM CAS-TKA) using the Medtronic electromagnetic navigation system. The results were compared with 45 matched patients with TKA performed with infrared navigation system (IR CAS-TKA) using BrainLAB Vector Vision CT-free Knee 1.5.1 version. The post-operative radiographic limb alignments were compared. We aimed to look for outlier in a more stringent way, so outlier was defined as more than two degrees of malalignment instead of three degrees conventionally.

Results: There was no significant difference in the age, sex distribution, pre-operative range of motion and pre-operative knee deformity. IR CAS-TKA had significantly less deviation from neutral alignment than EM TKA in femoral coronal plane \( (p < 0.001) \), tibial coronal plane \( (p = 0.04) \) and overall coronal plane \( (p = 0.006) \). EM-CAS TKA had significantly less deviation from neutral alignment in femoral sagittal plane than IR-CAS TKA \( (p = 0.049) \). Both groups had no significant difference in the tibial sagittal plane alignment. There were significantly more outliers in EM-CAS TKA group in femoral coronal planealignment.
Revision TKR and Tool Evaluation

(p < 0.001) and overall coronal plane alignment (p = 0.028). There was no significant difference in tourniquet time between the two groups (p = 0.113).

Discussion: IR CAS-TKA had significantly better alignment in femoral corona, tibial coronal and overall coronal plane than EM CAS-TKA. EM CAS-TKA had significantly better alignment in femoral sagittal plane than IR CAS-TKA. The more precise registration process of IR CAS-TKA system than EM CAS-TKA system may account for the higher accuracy. Both navigation systems could achieve good alignment but there was no single system which could achieve better result in all planes.

References

A Novel Force-based Tool For The Determination Of The Mikulicz-line In TKA

ELFRING R¹, TESKE W², DE LA FUENTE M², SCHMIDT F², NIGGEMEYER M², RADERMACHER K²

¹ Helmholtz-Institute For Biomedical Engineering, RWTH Aachen University, Aachen, Germany
² Department Of Orthopaedics, Ruhr University, Bochum, Germany

elfring@hia.rwth-aachen.de

Introduction: The alignment of the femoral component relative to the mechanical axis of the leg (Mikulicz-line) is one of the major tasks in Total Knee Arthroplasty. Several intra- and extramedullary alignment guides are available as well as kinematic or image-based approaches implemented in computer-aided surgical navigation systems. However, all of these techniques have disadvantages. Computer-aided approaches have proved to yield more accurate results [1], but require high investments, complicate the intervention and -according to most authors- prolong the operating time [1]. Besides the high invasiveness, conventional alignment guides suffer from inaccurate placing of the intramedullary rod [2].

A new approach has been developed at the Helmholtz-Institute Aachen using a simple and easy-to-use device to accurately determine the mechanical axis by mechanical means.

Materials and Methods: The new device ‘genALIGN’ uses a force-torque sensor to directly measure the torques induced by a deviation from the mechanical axis and visualizes the results on a screen.

After conventionally opening the knee, a pin is placed at the knee center (which is intra-operatively opened) to set up an unstable system with multiple joints (see figure). Applying a force \( F_z \) in direction of the knee, torques \( T_x \) and \( T_y \) occur whenever the joints are not coaxial with \( F_z \). Whenever \( T_x \) and \( T_y \) become zero, the system reaches an unstable equilibrium, with the device pointing exactly in direction of the mechanical axis. A graphical user interface enables the surgeon to intuitively align the device correctly. A small device at the tip of genALIGN
Revision TKR and Tool Evaluation

allows to fix the axis and to apply a cutting jig, enabling the surgeon to proceed with the intervention. Before the actual measurement is started, the sensor needs to be calibrated to eliminate the influence of the leg’s weight.

The system was evaluated in laboratory with different leg models (Sawbone AB, Sweden). An optical tracking system (Polaris, NDI, Canada) was used as a reference to track the known leg geometry. The deviation between the optically tracked axis and the axis determined with genALIGN was calculated. In order to prove the feasibility of this procedure under real conditions, a cadaver test was performed. Two knee joints of a fresh cadaver were opened according to the normal TKA procedure. The OrthoPilot navigation system (BBraun Aesculap, Germany) was used as a reference system. The genALIGN device was optically tracked to calculate its deviation from the reference line.

For weight compensation the thigh is supported with an elastically mounted strap such that the lower leg did not touch the table (see figure). Several users determined the mechanical leg axis with genALIGN.

Figure:
(a) Principle of operation of genALIGN. A deviation of the force Fz from the mechanical axis yields torques Tx and Ty, measured by the device.
(b) Cadaver study. In the center the device with a force-torque-sensor. The optical tracking is used as reference only.

Results: Laboratory tests showed the good performance of the genALIGN principle. Using the recent prototype of genALIGN, the axis could be determined with a deviation of 0.1°±1.1° (mean±std.dev.) varus and 0.1°±1.4° anterior slope by different users, compared to the optically tracked axis. Maximum deviation
was 3° varus and 4° anterior slope, respectively. Cadaver tests proved the feasibility of genALIGN. With the mechanical axis acquired by the OrthoPilot as reference, the Mikulicz-line could be determined with an accuracy of 2.9°±1.5° (mean±std.dev.) valgus and 0.3°±2.4° anterior slope in 48 measurements of four different users. Maximum deviation was 5° varus and 11° anterior slope. The accuracy was not user-dependent.

**Discussion:** GenALIGN offers an accurate, simple and low-cost approach for the determination of the Mikulicz-line in TKA. The alignment of the femoral component can be performed accurate and reliable without intramedullary devices and without a tracking system. The tracking system is only used as a reference during evaluations, but is not required for the measurement itself. The evaluation with cadaver tests confirmed the feasibility of the system. It became evident that the intra-operative handling has to be improved, in particular the weight-balancing.

Future work includes the replacement of the electronic Force-Torque-Sensor by a purely mechanical device, simplifying the intervention procedure as there will not be any need for a computer. Furthermore, the weight compensation of the leg will be enhanced. Even though the results are -due to calibration- not directly effected hereby, the handling will be improved.

**ACKNOWLEDGMENT:** This work has been funded in parts by the German Ministry for Education and Research (BMBF) in the framework of the OrthoMIT project under grant No. 01EQ0402.

**References**


The Short Term Results Of Robot-assisted Total Knee Arthroplasty - 1-4 Years Follow-up

LEE CT¹, YOON SH¹, KWON OM², TRABISH M², LEE HJ², PARK JS², KANG MR²

¹ Department Of Orthopedic Surgery, Lee Chun Tek Hospital, Suwon, Korea
² Lct Robotic Joint Research Center, Lee Chun Tek Hospital, Suwon, Korea

osman1973@hanmail.net

Introduction: The authors did not receive any outside funding or grants in support of their research for or preparation of this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, division, center, clinical practice, or other charitable or nonprofit organization with which the authors, or a member of their immediate families, are affiliated or associated.

The success of total knee arthroplasty (TKA) is dependent on many factors, including patient selection, implant design, implant positioning, soft tissue balancing, and surgical technique. Postoperative limb alignment and implant positioning are the most important determinants of outcome and longevity. There has been recent attention concerning computer-assisted TKA to improve implant positioning and limb alignment. However, we are not aware of many studies that have established whether robot-assisted TKA in alignment accuracy are associated with clinical and radiological results.

Materials and Methods: This study evaluated the short term results (1~4 years follow up) after robot-assisted TKA. 829 knees in 560 patients, who could be followed up more than 1 year after robot-assisted TKA from November 2002 to November 2006, were evaluated retrospectively. There were 503 women and 57 men with a mean age of 69 (47 to 86) years. The diagnosis was primary osteoarthritis in 743 knees, rheumatoid arthritis in 80 knees, osteonecrosis in 3 knees and post-traumatic arthritis in 3 knees. The operation was performed
with ROBODOC (ISS Inc., CA, USA) along with the ORTHODOC (ISS Inc., CA, USA) planning computer. Data collection, physical examination and radiographic evaluation were carried out at postoperative 3 months and annually. The clinical evaluations included the preoperative and postoperative range of motion (ROM), Knee Society Score (knee score, functional score) and postoperative complications. The radiological evaluations included tibiofemoral angle, implant position ($\alpha, \beta, \gamma, \delta$ angle) according to the system of Knee Society.

**Results:** The range of motion increased from preoperative mean 103.4 (±5.4, 35 to 130) to postoperative mean 123.3 (±7.4, 90 to 140) at the last follow up. Mean flexion contracture improved from 13.7 (±4.3, 0 to 50) to 0.8 (±2.3, 0 to 15) at the last follow up. The mean knee score and functional score improved from 35.4 (±10.3, 10 to 55) and 30.1 (±7.7, 10 to 60) before surgery to 90.6 (±5.8, 60 to 100) and 92.7 (±9.6, 60 to 100) after surgery at last follow up. The tibiofemoral angle changed from preoperative varus 13.1 (±6.3, -10 to 35) postoperative valgus 3.1 (±1.04, 1 to 7). The mean $\alpha, \beta, \gamma, \delta$ angle were 96.7 (±2.1, 90.2 to 104.5), 90.1 (±1.8, 81.3 to 98.2), 1.9 (±1.4, 0 to 4.8), 86.8 (±2.3, 80.3 to 89.7).

The complications were 14 cases of infection, 2 cases of patella tendon avulsion, 1 case of patella fracture, 1 case of femur shaft fracture, 2 cases of peroneal nerve palsy. 12 cases of infection were treated irrigation and debridement completely, and 2 cases of infection went to revision total knee arthroplasty after implant removal. Femur shaft fracture case was pin site fracture in severe osteoporotic patient and open reduction was performed by plate and screws. Peroneal nerve palsy was transient and healed spontaneously and we think that it was due to splint. We found no loosening and osteolysis at last follow up.

**Discussion:** On the basis of our results, we are cautiously optimistic about robot-assisted TKA. The short term follow up results after robot-assisted TKA
Revision TKR and Tool Evaluation

seemed to be satisfactory. What is more, the robot-assisted surgery was very useful especially in those cases of severely deformed knees and distorted anatomy. However, a long term follow up evaluation will be necessary and complications in our system (like pin site fracture) must be improved. We don’t think robot system is an end technology, but a step along the way to something bigger.
Early Clinical Results Of Robot Assisted Minimal Invasive Surgical Technology (RAMIST)

LEE CT¹, YOON SH¹, KWON OM², LEE JS², PARK JS², KANG M², TRABISH M²

¹ Department Of Orthopedic Surgery, Lee Chun Tek Hospital, Suwon, Korea
² Let Robotic Joint Research Center, Lee Chun Tek Hospital, Suwon, Korea

trabish@yahoo.com

Introduction: The authors did not receive any outside funding or grants in support of their research for or preparation of this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, division, center, clinical practice, or other charitable or nonprofit organization with which the authors, or a member of their immediate families, are affiliated or associated.

Robot-Assisted Minimal Invasive Surgical Technique (RAMIST) eliminates many factors that conventional minimal invasive surgery (MIS) techniques are known to have. The ultimate purpose of RAMIST is to reduce outliers in the success curve by replacing what the conventional MIS technique takes away from the surgeon that are critically important for repetitive excellent clinical results. Factors that are classified as benefits of MIS are cosmetic smaller incision, less blood loss, less vital soft tissue violation promoting a tissue sparing nature of an operation. Also introduced with conventional MIS are these factors which impair the surgeon’s visual, experience level with respect to the touch and feel accustomed by the surgeon, both of which could play a factor as to increase the outliers of the successes of all MIS procedures. These fall under categories such as less visibility, more stretching and retraction, difficulty precisely positioning bone cutting jigs which are prone to displacement due to external forces exerted on the jigs from surrounding soft tissue contact pressure, increased bruising. In order to preserve the crucial components of soft tissue sparing and at the same time implement a surgical plan that is always precise and accurate, RAMIST was born. Not only does RAMIST introduce a computer
Revision TKR and Tool Evaluation

alignment system, precision implementation is also a critical step to aid in the tissue sparing nature of the procedure. We hypothesized a Robot-Assisted MIS technique would out shine the conventional MIS gold standard for TKA by eliminating all MIS induced complications and adding several additions to the procedure that conventional MIS with computer assisted surgery (CAS) today is limited to performing.

**Materials and Methods:** 40 patients were randomly selected independent of all criteria such as patient weight, gender, flexion contracture, aggression of diseased state, all of which were indication of total knee arthroplasty (TKA) using either both standard long incision and/or the gold standard tissue sparing conventional MIS approach. Perioperative pain management was standardized. Incision sizes were measured intra-operatively and postoperatively, comfort of soft tissue management was noted intra-operatively, surgical time was noted, suture was also noted to detect soft tissue abrasion and stretching, radiological evaluation was done postoperatively, hip-knee-ankle (HKA) alignments were documented, implant position including $\alpha$, $\beta$, $\gamma$, $\delta$ angles were precisely measured and documented. Patient comfort level including pain intensity and mobility immediate post-op were closely monitored.

**Results:** In order to attain adequate entry for the robot without any extensive soft tissue retraction an average incision size of 8.2cm was measured. Comfort of soft tissue retraction was noted to be extremely low compared with what
normally experienced during conventional MIS procedures. Incision to suture surgical times was averaged at 1 hour 15 minutes. In all cases no abrasion or skin stretching was observed. Upon reviewing radiological data HKA alignments had a mean value 1.3 degrees with no outliers. Mean $\alpha$, $\beta$, $\gamma$, $\delta$ angles were 96.3 ($\pm$3.6, 92.0 to 101), 90.6 ($\pm$1.6, 87.5 to 94.4), 0.0 ($\pm$0.0), 89.0 ($\pm$2.3, 84.3 to 92.9) respectively. All patients were able to perform self leg-raising mobility function exercises immediate post-op after 2 hours which was the beginning of their recovery regime. Immediate post-op evaluation revealed that the average time for comfortable full weight bearing was 4 hours with slight pain. This was seen for all patients included in the study with no exclusions. Also documented was that all patients able to stand after 4 hours post-op were also able to walk with slight discomfort. After 5 days post-op all patients included in the study had ROM greater than 110 deg on flexion.

Discussion: Due to the tissue sparing nature of Robot-Assisted Minimal Invasive Surgical Technology (RAMIST) all bony surface cuts can be done within a 8.2 cm incision size without any retraction of the surrounding soft tissue. Key issue at hand is that RAMIST requires the surgeon to prepare only the access for the robot tool tip. In comparison to the conventional MIS approach, a surgeon is also required to extensively retract surrounding tissue even through a limited incision to adequately place the jigs and apparatus for bony surface cuts. Failure point being such that external forces exerted onto the jig could likely displace the jig resulting in poor bony surface cuts as well as increased soft tissue bruising and abrasion, all of which are well documented in association with standard MIS techniques.
Which CAOS Systems Can Deliver Adequate Accuracy And Precision In Hip Resurfacing?

Cobb JP, Kannan V, Dandachi W

Orthopaedic Surgery, Imperial College, London, UK

j.cobb@imperial.ac.uk

Introduction: The variations in anatomy of cam type hips pose technical problems for inexperienced surgeons attempting hip resurfacing. CAOS systems have an opportunity to gain widespread acceptance in this demanding procedure if they are as good as they claim. To be fit for purpose, we considered that a system should deliver both angular alignment and translation, with 95% of cases lying within +/-10° and +/- 6mm of the optimal position, and orientation.

Materials and Methods: A prospective randomized control trial was designed to show which of the current systems were able to allow novice surgeons to deliver appropriate accuracy and precision with a minimal learning curve. Medical students who were studying surgical technology, and who had been taught the principles of hip resurfacing and how to plan the operation were instructed in both two dimensional planning based upon plane radiographs using acetate templates, and 3 dimensional planning using a CT dataset and a hip planner (version 1.2.1, Acrobot, London, UK). By combining the two-dimensional and three-dimensional visualization in the planner, the students were shown that it was possible to make very small adjustments to optimise the fit of both components, avoiding oversizing, notching, or angular malpositioning. Models were made based upon the CT datasets of 3 patients representing different types of cam type deformity. The optimal position and angulation for each type of hip were established using the rules established in earlier work.

Mild cam type, with a small amount of posterior and inferior head on neck angulation.

Moderate cam type, with a greater degree of posterior and inferior head on neck angulation, resembling a pistol grip deformity.

Severe cam type, with some neck shortening and a marked anterior boss in addition to posterior and inferior angular deformity.
The students were given the task of inserting a guide wire into the optimal position of a femoral head using 3 different methods:

1) conventional instruments supplied by the manufacturer (Corin, Cirencester UK).

2) an imageless navigation system (Brainlab essential hip 5.0, Westchester, Illinois).

3) an image-based navigation system (Acrobot Co Ltd, London, UK). This is a low dose computerized tomography based navigation system which uses two digitizing arms instead of optical tracking technology.

A custom-designed lower limb work station (Medical Models, London, UK) was used to hold the dry bones. This allows the proximal femur inserts to be mounted, and fixed to the table in the lateral position representing the way a femur would be offered up if a posterior approach was used.

The three-dimensional plans were used independently in the conventional and image free station and incorporated within the image-based navigation software as the target position. Students were not asked to modify the plan, but were simply given the plan and asked to achieve it using the technology provided.

After completion of the tasks, all bones from the three stations were re-registered using the method described by one of the authors, and the wayfinder system used to measure the trajectory and offset of the entry point from the target position.

The guide wire error was measured in all 4 degrees of freedom: inclination, version, antero-posterior, and supero-inferior translation. The Mann-Whitney U test was used for comparison of non-parametric variables between groups: inclination error, version error, and translation errors. The effect of abnormal femoral morphology on the three stations was also compared.
**Results:** All students completed the tasks required. No detailed record of time was taken, to avoid exerting any time pressure.

Angulation: Accurate angulation was delivered by both image free navigation (mean varus inclination error (MIE) of 0° and mean varus error (MVE) of 0°) and image based navigation (MIE of 1° and a MVE of -1°). Conventional instruments were significantly less accurate (MIE of 4° and MIE -2°) than either navigation method.

Precision in inclination was also delivered by both image free navigation (inclination standard deviation (ISD) of 2°) and image based navigation (ISD of 1°). Conventional instrumentation was less precise (ISD 4°). Precision in version was only delivered by image based navigation (version standard deviation (VSD) of 2°). Conventional instrumentation was significantly less precise (VSD 5°), and image based navigation significantly less precise again (9°).

Translation: Both image based and image free navigation were accurate in translation in the anterior-posterior plane, delivering a mean posterior entry point error (MPE) of around 1mm, while conventional instruments were less accurate (MPE of 3mm). Image based navigation was accurate in the supero-inferior plane, delivering an inferior entry point error (MIE) of 0mm, while image free navigation (MIE of 2mm) and conventional instruments (MIE of 2mm) were both significantly less accurate.

Only image based navigation delivered precision in translation. The image based standard deviation of entry point inferiorly was (ISD 1.1mm). Image free navigation was significantly less precise (ISD 2.1mm). Conventional instruments were much less precise again (ISD 4.4mm). In the posterior direction, image based navigation was once again precise (PSD 1.6mm), but neither of the other two methods delivered posterior translation with precision. Conventional instruments were significantly more precise (PSD 3.4mm) than image free navigation (PSD 6.2mm).

**Table 1:** the accuracy and precision delivered by 3 systems

<table>
<thead>
<tr>
<th></th>
<th>Accuracy Limits (mean within +/- 10°, 6mm)</th>
<th>Precision Limits (95% within +/- 10°, 6mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Yes (2°, 6mm)</td>
<td>No (10°, 9mm)</td>
</tr>
<tr>
<td>Image free</td>
<td>Yes (0°, 4mm)</td>
<td>No (18°, 12mm)</td>
</tr>
<tr>
<td>Image based</td>
<td>Yes (1°, 2mm)</td>
<td>Yes (4°, 3.2mm)</td>
</tr>
</tbody>
</table>
**Discussion:** Image based navigation delivered sufficient accuracy and precision for even novice surgeons to achieve the required levels of performance of this demanding operation. Neither conventional instruments, nor image free systems were precise enough to deal with the variations in anatomy found in cam type hips. As an aid for novice surgeons seeking to achieve expert level skills 95% of the time, image based systems are fit for purpose.
Evaluation On The Functionality And Accuracy Of A New Fluoroscopic-based Navigation System For Implantation Of The Femoral Component In Hip Resurfacing: An In-vitro And Cadaver Study Within The Scope Of The ORTHOMIT-project

GRAVIUS S¹, BELEI P², DE LA FUENTE M², MÜLLER-RATH R³, RADERMACHER K², WIRTZ DC¹, MUMME T³

¹ Department Of Orthopaedic And Trauma Surgery, University Hospital Bonn, Bonn, Germany
² Helmholtz-institute For Biomedical Engineering, Rwth Aachen University, Aachen, Germany
³ Department Of Orthopaedic Surgery, University Hospital Aachen, Aachen, Germany

sascha.gravius@web.de

Introduction: The most essential improvements of modern hip resurfacing arthroplasty are the metal-on-metal bearing as well as the integration of a procedure for the exact and reproducible positioning of the femoral component using specific mechanical alignment instruments [1]. Main reasons for early implant failure are mal-positioning of the femoral component and notching of the femoral neck during femoral head preparation. In order to prevent early implant failure or limitations affecting the patient’s range of motion, it is important to implant the femoral component respecting the following criteria:

- valgus positioning of +5° in accordance to the preoperative neck-shaft-angle
- avoiding femoral neck notching
- anterior positioning to avoid femoroacetabular impingement
To support the surgeon in the planning and implantation of the femoral component, a new fluoroscopic computer-assisted planning and navigation system based on optical tracking as well as intraoperative calibrated X-ray images has been developed. The system has been implemented on the basis of a navigation module library from SurgiTAIX AG (Aachen, Germany).

This paper presents the results of an in-vitro and cadaver study on the functionality and accuracy of the system in comparison to the usage of a conventional prosthesis-specific mechanical alignment instrument.

**Materials and Methods:** For the in-vitro evaluation of this approach, 10 DUROM™-Hip-Resurfacing prostheses (Zimmer GmbH, Freiburg, Germany) were implanted with the prosthesis-specific mechanical alignment instrument while 10 prostheses were implanted under navigation control. Each implantation has been realized using artificial femur bones (Type „Composite Femur“ Nr. 3306, SAWBONES® EUROPE AB, Malmoe, S). Additionally, 6 prostheses have been implanted into femora of three formalin-fixed cadaveric full body specimens via a lateral approach in a supine position.

Prosthesis-specific mechanical alignment instrument:
The implantation of the femoral resurfacing prosthesis has been carried out in accordance to the manufacturer’s guidelines for the implantation of the hip resurfacing system by using the prosthesis-specific mechanical alignment device.

Computer-assisted fluoroscopic planning and navigation system:
After fixation of the dynamic reference base (DRB) on the proximal part of the femur, the surgeon executed the following planning and navigation steps:

Initially, a transcortaneous palpation of three points (medial and lateral epicondyle and the greater trochanter) is used to compute the eye-hand coordinate transformation for an intuitive representation of the tracked tools during drilling of the guide pin. These three points are then used for non-rigid point-to-point registration of a simplified bone shape model necessary for the “Zero-dose C-Arm navigation” (SurgiTAIX AG, Aachen, Germany) during the image acquisition step. Here, at least two calibrated X-rays have to be acquired (a.p and Lauenstein). The “Zero-dose C-Arm navigation” enables a virtual radiation-free preview of the X-Ray images. In the next step, the definition of a 3D “safe zone” helps the surgeon to plan the final position of the prosthesis. A non-invasive approximation of the femoral neck anatomy using an adaptable
cylinder is used here. Additionally, an optional registration of critical areas on the femoral neck that could lead to femoral notching is possible. In order to plan the final implant position, 3D models as well as profile models of the femoral implant from a database are matched to the fluoroscopic images. To avoid femoral notching, the goal of this planning step is to find a valid implant position with respect to the general boundary conditions, including a valgus position from $+5^\circ$ in accordance to the preoperative neck-shaft-angle and an anterior positioning of the femoral implant, without leaving the predefined safe zone. For the image-guided free hand navigation an optical tracking system is used which permanently tracks the position of the drilling machine. During the navigation step the surgeon is supported by a compensatory display incorporating two cross-hair-like indicators representing the tool orientation.

**Results:** The main angulation error between planning and navigation was $1.2 \pm 0.6^\circ$ in-vitro and $1.9 \pm 1.2^\circ$ in the cadaver study for the navigation system vs. $6.5 \pm 5.5^\circ$ / $8.4 \pm 7^\circ$ for the mechanical alignment instrument, the main anterior offset error was $0.6 \pm 0.8$ mm / $0.8 \pm 0.9$ mm vs. $0.7 \pm 3.1$ mm / $1.5 \pm 3.9$ mm. The additional time for all five planning and navigation steps was $2.7 \pm 2.3$ min in-vitro and $2.3 \pm 1.9$ min in the cadaver study controversial to the mechanical alignment instrument, the main distance error was $1.8 \pm 0.5$ mm / $2.5 \pm 1$ mm vs. $5.3 \pm 2.4$ mm / $7 \pm 4.5$ mm. Neither for navigational nor conventional implantation femoral notching could be observed.

**Discussion:** The computer-assisted fluoroscopic planning and navigation system for hip resurfacing showed - within the scope of this study - first promising results. The system enables a practicable planning with a high accuracy in implementation. Particularly the general boundary condition to implant the femoral prosthesis in a valgus position from $+5^\circ$ in accordance to the preoperative neck-shaft-angle as well as the anterior positioning to avoid a femoroacetabular impingement could be realized with a high precision controversial to the prosthesis-specific mechanical alignment instrument. However, the overall system accuracy could be increased as that was already reported in a previous cadaver study [2]. Here, the algorithm of X-ray image calibration could be identified as one possible source of error. The potential benefit of the computer-assisted fluoroscopic planning and navigation system has to be evaluated in further clinical studies, especially from the perspective of a possible integration of this navigation system into the clinical workflow.

**Acknowledgment:** This work has been founded in parts by the German Federal Ministry of Education and Research (BMBF) in the framework of the OrthoMIT Femoral Head Resurfacing
project under grant No. BMBF 01EQ0402 / BMBF 01IBE02C. Additionally, the authors wish to thank the chair of anatomy of the Rheinische-Friedrich-Wilhelm university of Bonn realization the cadaver study.

References


Imageless Navigation In Hip Resurfacing: Avoiding Component Malposition During The Surgeon Learning Curve

ROMANOWSKI JR¹, SWANK ML²

¹ Department Of Orthopaedic Surgery, University Of Cincinnati, Cincinnati, OH, USA
² Cincinnati Orthopaedic Research Institute, Cincinnati, OH, USA
jamroman@yahoo.com

Introduction: Total hip arthroplasty remains one of the most successful orthopaedic procedures. Evolution of implant design and patient demand have led to advances in componentry, namely hip resurfacing arthroplasty. Hip resurfacing is inherently more complex than traditional total hip arthroplasty given the limited femoral resection that makes cup visualization difficult. Minimally invasive techniques have received a considerable amount of attention, adding further technical challenges.¹

Accurate component placement is essential, and deviation of implant alignment has been shown to negatively affect wear rates and decrease the safe range of motion, creating an unfavorable situation of impingement with subsequent increase in dislocations.² The etiology can be multifactorial, but proper component positioning and soft tissue tensioning remain crucial in preventing hip instability.³ A common indication for revision total hip arthroplasty is recurrent dislocation. Given the critical nature of implant positioning, computer assisted navigation has found an increased role in the setting of joint arthroplasty.

Computer assisted navigation addresses these challenges through both hardware and software design innovations. The instruments are available in various low profile dimensions and curves that may be used depending on the particular position of the femur or desired mapping surface. Software features provide a means of targeting drill guides and adjusting alignment parameters affecting component positions. With the ability to topographically map the native joint anatomy and provide “real time” feedback on intra-operative
implant coordinates, computer assisted surgery (CAS) potentially decreases the influence of the surgeon's own subjective judgment and eliminates the use of mechanical alignment devices.

Particular attention has recently focused on specialty hospitals and the role of surgeon experience in optimizing patient outcomes. Studies have shown that physicians with high volume arthroplasty practices have significantly lower rates of dislocation. Significant credit has been given to surgeon experience and subsequent improvement of component placement in improving this patient outcome. It is clinically unknown if traditional lessons learned over the course of a surgeon’s experience can be appreciated earlier in the “learning curve” through the assistance of computer navigation.

The purpose of this study is to evaluate the impact of computer navigation over the course of a surgeon’s entire hip resurfacing arthroplasty experience as measured by both intra-operative and post-operative component alignment parameters. Furthermore, this study attempts to validate computer navigation as a reliable method for consistent post-operative radiographic component alignment.

Materials and Methods: A prospective review of 71 consecutive hip resurfacing arthroplasties placed with computer assisted navigation during 2006 and 2007 was performed. Intra-operative femoral and acetabular component parameters were compared to post-operative radiographic alignment values. Within this single surgeon series, operative time, intra-operative cup inclination and femoral stem/shaft angles, as well as post-operative cup inclination and femoral stem/shaft angles were also measured and compared over the course of three discreet, sequential operative time periods. Patient demographic data and surgical parameters including blood loss, surgical approach and anesthesia time were recorded (Table 1).

Results: Intra-operative cup inclination angles were comparable to post-operative radiographic values as there was no significant difference (p=.059). A statistically significant difference existed between intraoperative femoral stem/shaft angles compared to post-operative radiographs measurements (p<.001), however, all means maintained a significant valgus orientation compared to the native neck angle. Computer assisted navigation produced consistent values despite different levels of surgeon experience in the setting of intra-operative cup inclination (42.8°, 43.5°, and 40.1°; p=0.362) and post-operative cup (46.1°, 43.9°, and 42.9°; p=0.411) and femoral stem (147.9°, 146.5°, and 144.0°; p=0.097) radiographic alignment. Operative times significantly decreased with surgeon experience, showing the largest decrease after the 1st sequence interval (109.6,
97.8, and 94.8 minutes, respectively). There was a significant difference with evolving surgeon experience concerning intra-operative stem placement (143.5°, 142.1°, and 138.0°; p<.001) despite the mean values remaining well clustered (Table 2). No femoral notching (0/71) occurred throughout the series.

<table>
<thead>
<tr>
<th>Demographic Parameter</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean ±SD)</td>
<td>49.7±7.1 years (range 19-61)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>54/71 (76.1%)</td>
</tr>
<tr>
<td>Female</td>
<td>17/71 (23.9%)</td>
</tr>
<tr>
<td>Height (mean±SD)</td>
<td>70.2±3.9 in. (range 61-79)</td>
</tr>
<tr>
<td>Weight (mean±SD)</td>
<td>210.2±39.7 lbs. (range 134-296)</td>
</tr>
<tr>
<td>Operative Side</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>24/71 (33.8%)</td>
</tr>
<tr>
<td>Right</td>
<td>47/71 (66.2%)</td>
</tr>
<tr>
<td>Length of Stay (mean±SD)</td>
<td>2.3±1.8 days (range 1-17)</td>
</tr>
<tr>
<td>Blood Loss</td>
<td>390.1±179.2 mL (range 100-1000)</td>
</tr>
<tr>
<td>Anesthesia Time (mean±SD)</td>
<td>144.8±22.3 min. (range 110-245)</td>
</tr>
<tr>
<td>Operative Time (mean±SD)</td>
<td>100.4±19.5 min. (range 70-180)</td>
</tr>
</tbody>
</table>

Linear regression values of measured parameters versus surgeon experience.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correlation Coefficient</th>
<th>Intercept</th>
<th>Slope</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative Time</td>
<td>0.385</td>
<td>114.9</td>
<td>0.573</td>
<td>0.001</td>
</tr>
<tr>
<td>Cup inclination (Post-operative)</td>
<td>0.100</td>
<td>45.43</td>
<td>-0.047</td>
<td>0.411</td>
</tr>
<tr>
<td>FSA (Post-operative)</td>
<td>0.200</td>
<td>148.6</td>
<td>-0.101</td>
<td>0.097</td>
</tr>
<tr>
<td>Cup inclination (Intra-operative)</td>
<td>0.128</td>
<td>43.39</td>
<td>-0.053</td>
<td>0.362</td>
</tr>
<tr>
<td>FSA (Intra-operative)</td>
<td>0.463</td>
<td>145.1</td>
<td>-0.159</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Discussion: Computer assisted navigation provides a dependable method of accurate hip resurfacing arthroplasty component positioning as measured by cup inclination, as well as reliable technique for valgus stem placement and avoidance of notching. Furthermore, computer navigation allows for consistency and offers a protective affect on component alignment independent of procedural experience.

References

Navigation In Thoracic Spine (T 1-10) - Useful Tool Or Toy For The Surgeon?

KATSCHER S, JARVERS JS, RIESNER HJ, FRANCK A, BLATTER T, JOSTEN C

Department Of Traumatology And Spine Surgery, University Of Leipzig, Germany

Sebastian.Katscher@medizin.uni-leipzig.de

Introduction: Navigation of pedicle screws in the lower part of the thoracic, thoracolumbar and lumbar spine has become a well established method during the last years. But the accuracy of navigation was still insufficient for an exact placement of pedicle screws in the upper and middle part of the thoracic spine with thin pedicles. This prospective study is dealing with the question weather or not new matching software for the use of preoperative CT as well as intraoperative 3D-navigation with 3D fluoroscopy is able to increase the accuracy of pedicle screw placement in these parts.

Materials and Methods: In preclinical examination the new technique was established in human cadavers (n=2), and then it was used in 27 patients. Out of these 27 patients cause for stabilisation were fractures (n=15), spondylodiscitis (n=5), and metastases (n=7). The area of navigated dorsal instrumentation with internal fixator was T1 to T10. Each time minimal two vertebral bodies above and below the lesion were included into stabilisation. In 17 cases we used preoperative CT-scans with the “region based surface matching” (Vector Vision, Fa. Brainlab) and in the other 10 cases intraoperative 3D scan with 3D fluoroscope (Vision Vario 3D, Fa. Ziehm) was taken for data collection and navigation. Pedicle preparation was achieved by navigated awles, then screw insertion were performed and final screenshots were taken. The precision of the pedicle screws was checked in some cases by intraoperative 3D scan an in all by a postoperative CT-scan.

Results: In cases with intraoperative 3D scan always 2 scans for planning were necessary - one above and one below the lesion. A total number of 180/216 thoracic pedicle screws (83.3%) were navigated. For the other 36 screws no exacts matching (accuracy < 1 mm) was possible or there were various techni-
cal problems with the intraoperative 3D scan. Postoperative CT-scan showed a central location of the pedicle screw in 196/216 cases (90.7%). The position of navigated screws in the CT-scan was the same as seen in the intraoperative screenshots. In 20/216 (9.3%) the actual position of the pedicle screw differed from the one seen in the screenshots within 5 degrees in axis. They were perforating the pedicle medially or laterally by less than 2 mm - no vascular or neurological complication occurred and no revision surgery was needed.

Discussion: In the middle and upper part of the thoracic vertebrae the percentage of screws that were seen to be placed incorrectly was low (9.3%), especially considering that no revision was needed. However it is still unsatisfying that there is still a some percentage of mismatches that led to a prolonged time of surgery and sometimes to the impossibility of screw navigation (36/216 = 16.6%). Problems often are obesity and osteoporosis. With a higher quality of CT-scans or intraoperative 3D imaging and navigation software these problems can be reduced. Nevertheless these devices in the hands of a careful surgeon lead to a greater safety while placing the pedicle screws in the middle and upper part of the thoracic spine.
3D-Fluoroscopy Guidance For Thoracic And Lumbar Fractures

Grützner PA¹, Wentzen A², Nolte LP³, Von Recum F³

¹ Katharinenhospital Stuttgart, Department for Trauma and Orthopaedic Surgery, Stuttgart, Germany
² BG Trauma Center Ludwigshafen, University of Heidelberg, Germany
³ MEM Research Center, ISTB, University of Bern, Switzerland

P.Gruetzner@klinikum-stuttgart.de

Introduction: In 1994 CT based spinal navigation systems have been introduced for insertion of transpedicular screws. In order to improve the workflow 2D Fluoro-navigation was proposed, however with significant limitations to the imaging information. As an alternative to these technologies 3D Fluoro-navigation was introduced linking new mobile imaging Fluoro-CT devices with established spinal navigation systems. The Fluoro-CT device permits the intraoperative three-dimensional representation of bone structures by means of a high-resolution isotropic 3D data cube with an edge length of approximately 12 cm. In the course of this prospective study 3D Fluoro-navigation was used for the insertion of transpedicular screws.

Materials and Methods: 71 patients (26 female / 45 male) with spinal fractures (40 lumbar / 31 thoracic) were treated. An angular stable instrumentation system was used (USS, Synthes, Oberdorf, CH). As part of a conventional dorsal approach registered images were taken with the Fluoro-CT device (ISO-C-3D Siemens Medical Solutions, Erlangen, D) and transferred to the SurgiGATE Spine navigation system (Praxim/Medivision, Grenoble, F). In order to compensate for motion artifacts in particular due to breathing Apnea was enforced after pre-oxygenation with 100% oxygen. Screw trajectories were planned and a thorough verification procedure performed. Screws were inserted using tracked instruments. The four surgeons involved were experienced navigation users. A standardized protocol was applied for studying the placement accuracy in postoperative CTs. In addition a variety of surgical parameters were studied.
**Results:** A total of 359 screws (175 lumbar / 184 thoracic) were placed. No misplacements were observed for the lumbar region. Thoracic misplacement were [2-3mm - n=3] and [3-4mm - n=2]. No substantial misplacements (>4mm) were detected and no postoperative neurological complications observed. OR-time was 99min (SD 42min) with mean X-ray exposure of 1.53min (SD 0.75min) Fluoro-time.

**Discussion:** In the hands of experienced surgeons 3D Fluoro navigation is a safe and reliable technique for the precise placement of transpedicular screws. It provides important intraoperative image information and allows reducing X-ray exposure without relevant increase of OR-time.
Fluoroscopy-based Navigation System In Spine Surgery

Merloz P¹, Trocaz F, Vouallat H¹, Vasile C¹, Tonetti J¹, Eid A¹, Sadok B¹, Van Overschelde J¹

¹ Department Of Surgery, Chu Michallon, Grenoble, France
² In3s Laboratory, Joseph Fourier University, Grenoble, France

PMerloz@chu-grenoble.fr

Introduction: Transpedicle screw insertion is commonly used for rigid segmental fixation for various spine disorders, including fractures, scoliosis, spondylolisthesis and degenerative instabilities. Previous studies of surgical procedures have shown a significant rate of incorrect placement (screws that extended less than 2 mm beyond the pedicle cortical bone were considered as misplaced) of pedicle screws ranging from 20 % to 40 % (Weinstein JN et al. [1988], Jerosch J et al. [1993], Sim E [1993], Vaccaro et al. [1995]).

Mobile fluoroscopic devices are an integral part of the standard equipment used in orthopaedic surgery to provide real-time feedback of bone and surgical tool positions. One of the disadvantages of this technique includes the need for continuous radiation exposure for real-time visual control. The aim of this paper is to describe a computer-assisted surgical navigation system based on fluoroscopic X-ray image calibration and 3D optical localizers in order to reduce radiation exposure while increasing accuracy and reliability of the surgical procedure for pedicle screw insertion.

Materials and Methods: Instrumentation using transpedicular screw fixation was performed in the thoraco lumbar region. In a first group, a conventional surgical procedure was done with 26 patients (138 screws; T11 - L5); in a second group, a navigated surgical procedure (virtual fluoroscopy) was done with 26 patients (140 screws; T8 - L5). Evaluation of screw placement in every case was done by using plain X rays and post operative CT scan, with the help of an independent examiner (radiologist). The selection criteria between good and bad placement of the pedicle screw is the level of cortex penetration. According to Fu TS et al. [2000] cortex penetration of the screw measured on a
CT scan above 1 mm is considered as an incorrect placement.

**Results:** A percentage of cortex penetration of 5% (7 of 140 pedicle screws) occurred for the computer-assisted group. A percentage of penetration of 13% (18 of 138 pedicle screws) occurred for the non computer-assisted group. The radiation running time for each vertebra level (two screws) is reaching 3.5 seconds on the average in the computer-assisted group and 11.5 seconds on the average in the non computer-assisted group. The operative time for two screws on the same vertebra level reaches 10 minutes on the average in the non computer-assisted group and 11.9 minutes on the average in the computer-assisted group.

**Discussion:** We found good accuracy of screw insertion using fluoroscopy-based navigation system, as compared to the results of conventional technique. In the current study, 7 of 140 (5%) pedicle screws were considered to be misplaced when using 2-D fluoroscopic navigation. No cortical violation was found in the sagittal plane. The results were really superior to the conventional procedure in the prevention of cortical violation in the sagittal plane. Our results show the limitation of the computer-assisted fluoroscopy-guided system: it only offers navigation in two-dimension images. The most common trajectory for pedicle violations was on the axial plane. The choice of insertion angle in the axial plane has always been determined by the judgment of the surgeon. It is well known that the computer-assisted procedure is slightly time consuming as reported by Fu TS et al. [2004]. The main reasons for time increasing are the following: setup, reference frame attachment and data acquisition.

The average radiation running time for each vertebra level (two screws) was 3.5 seconds on the average in the computer-assisted group, compared to the 11 mn 30 sec. of radiation running time in the non computer-assisted group. As reported by Foley KT et al. [2000] in spine surgery, the fluoroscopy-based computer system can reduce significantly radiation exposure of both patient and surgical staff.

A fluoroscopy-based computer system can be seen as a complement or an alternative to the use of a CT-based computer system (CT scans provide full 3D image data, not fluoroscopic images). The advantages over CT-based systems are twofold: instant availability without preoperative preparation (no CT acquisition required) and up-to-date image data of patient anatomy (X-ray images used for navigation are acquired at the beginning of surgical procedure).
The fluoroscopy-based (2-D) navigation system for pedicle screw insertion is a safe and reliable procedure for spine surgery in the lower thoracic and lumbar spine.

Cost and additional time might very well be compensated by the significant outlier reduction in screw placement.
Computer Assisted Tumor Surgery (CATS): A New Application In Caos

WONG KC¹, KUMTA SM², ANTONIO GE³, NG WK⁴, LEE KS⁴, TSE LF²

¹ Department Of Orthopaedics And Traumatology, Alice Ho Nethersole Hospital, Hong Kong, China
² Department Of Orthopaedics And Traumatology, Prince Of Wales Hospital, The Chinese University Of Hong Kong, Hong Kong, China
³ Department Of Diagnostic Radiology And Organ Imaging, Prince Of Wales Hospital, Hong Kong, China
⁴ Acaos-itav Team, Department Of Orthopaedics And Traumatology, Prince Of Wales Hospital, Hong Kong, China

skcwong@ort.cuhk.edu.hk

Introduction: Computer navigation had been effectively used in joint replacement, spinal surgery and orthopaedic trauma. The use of this technique in musculoskeletal bone tumors had recently been reported in small case series.¹⁻⁴ Tumor surgeons had to integrate all preoperative images and formulate mentally a surgical plan. Computer navigation facilitated this mental process and supported the analysis and execution of planned tumor resection. Precise tumor resection and bone reconstruction ensured the best oncological and functional outcome. This study was to investigate the feasibility of computer navigation in assisting surgical planning and execution of bone tumor resection and reconstruction.

Materials and Methods: Between March 2006 and October 2007, 16 bone tumors in 14 patients were operated under navigational guidance. The mean age of patients was 40.6 (6 to 80). There were 4 pelvic metastases, 7 sacral tumors, 4 femur and 1 tibia tumor. Navigational guidance was required because of difficulties in precise tumor resection and reconstruction with custom tumor prostheses. Preoperative CT and MRI scan of each patient were taken and image fusion was performed in 13 cases by navigation software (Stryker navigation, CT spine). CT angiogram and PET scan were also integrated into fused images whenever they were necessary for tumor definition and surgical planning. Tumor extent was determined in the fused image data sets. A 3D bone
tumor planning model was obtained. Resection information to accommodate CAD custom tumor prostheses was incorporated in 6 cases. The plane of tumor resection was then determined and marked using multiple virtual pedicle screws along the planned resection margin. After satisfactory image-to-patient registration by paired points and surface matching, the position of virtual pedicle screws along the planned resection was located by navigation probe or instruments mounted with navigation trackers. Tumors were then removed by osteotomes or oscillating saws. We recorded the time for preoperative planning and intraoperative navigational procedures; image-to-patient registration error; histological evaluation of tumor margin in resected specimens; oncological result; postoperative alignment of custom tumor prosthesis.

Results: The CT-MRI image fusion was successfully performed and facilitated the preoperative navigational planning in 13 cases. It took an average of 2.4 hours (1.1 to 6.0) while intraoperative navigation took 25.6 minutes (13 to 50). The mean image-to-patient registration error was 0.42mm (0.35 to 0.68). All cases could be executed as planned under navigational guidance. Histological examination of all resected specimens showed a clear tumor margin. Radiological examination of patients reconstructed with CAD custom tumor prostheses confirmed satisfactory implants’ alignment. No patients experienced local recurrence.

Discussion: Computer navigation had been commonly used in cranio-maxillofacial tumor surgery but rarely in musculoskeletal tumor surgery. Though there was no navigation software dedicated to bone tumor, the study showed that same navigation workflow could be successfully applied in bone tumor resection and reconstruction. Image fusion of multimodal image data sets offered surgeons a new and interactive analysis of tumor extent. It greatly facilitated surgical and navigational planning. This formed one of the critical steps in navigation assisted bone tumor surgery. Image-to-patient registration of all cases was accurate though the CT based navigation system was originally designed for pedicle screws insertion in spinal surgery. It then allowed execution of planned resection under navigational guidance. The study showed that CATS could improve the intraoperative visualization and orientation of tumor location. It thus allowed precise execution of planned resection and reconstruction and might reduce human error. Surgeons
required a full understanding of navigational principles and workflow to avoid misinterpretation of navigational information during surgery.

In conclusion, computer assisted surgery was feasible and helpful in complex bone tumor resection and reconstruction, such as pelvic, sacral or joint saving resection and custom tumor prosthetic reconstruction. A user-friendly navigational software and instruments dedicated to CATS was required to popularize this new application in CAOS.

References


Introduction: The pivot-shift clinical test is commonly used for the qualitative
dynamic evaluation of the translational and rotational knee instability and can be a useful indicator in the prediction of later osteoarthritis [1]. With the aim of controlling the static antero-posterior knee instability as also tibial subluxation (highlighted with pivot-shift test) many surgeons have started performing anatomical double-bundle (DB) reconstructions, thus trying to reproduce with the surgery the anatomy and complex functions of the native ACL [1]. In fact the literature suggests that an anatomical DB ACL reconstruction could have some advantages in clinical outcome [2, 3]. Although different studies reported, at a mid term follow up, the superior results of the DB bundle reconstruction with respect to the Lachman’s test and pivot-shift phenomenon after, they did not provided quantitative assessment about the global laxity. The objective of this study was thus to quantify intra-operatively the improvements in knee stability and knee kinematics due to an anatomical DB reconstruction [3].

Materials and Methods: Fifteen patients (32.8±7.6 y) with isolated anterior cruciate ligament injury, that consecutively underwent anatomical DB ACL reconstruction, were included in this preliminary study. To evaluate the joint laxity and kinematics we used an optical navigation system focused in kinematic acquisitions [4]. After tunnel drilling and before graft fixation, the operating surgeon performed manually clinical tests at maximum force: valgus/varus (VV) rotation at 0° and 30° of flexion, internal/external (IE) rotation at 30° and 90° of flexion, antero/posterior (AP) displacement at 30° and 90° of flexion and pivot-shift test. Anatomical double-bundle ACL reconstruction was, then, performed [2] and the same kinematic tests were re-acquired. The
surgeon was blinded on test results; the whole set of the kinematic data was off-line elaborated. Statistical analysis was performed comparing data derived from stress tests performed before and after reconstruction (fig. 1). For what concerns pivot-shift test we analysed the decomposition of three different parameters with respect to flexion/extension angle: AP translation, IE and VV rotations. For each decomposition we evaluated the areas included by the curves (the ‘hysteresis’ of the joint due to positive pivot-shift) and the difference in the peaks before and after the surgery at a specific flexion angle. A typical result is shown in fig. 2. Comparisons between pre- and post-op levels of laxity and of pivot shift were made using paired Student’s t-test (p<0.05).

**Results:** The differences in laxity before and after reconstruction is shown in table 1. All laxities were significantly reduced by the anatomical DB reconstruction (p<0.01).

<table>
<thead>
<tr>
<th>TEST</th>
<th>PRE</th>
<th>POST</th>
</tr>
</thead>
<tbody>
<tr>
<td>VV 0 [°]</td>
<td>5.4 ± 1.3</td>
<td>3.0 ± 1.1</td>
</tr>
<tr>
<td>VV 30 [°]</td>
<td>4.4 ± 1.9</td>
<td>3.3 ± 1.1</td>
</tr>
<tr>
<td>AP 30 [mm]</td>
<td>11.9 ± 1.8</td>
<td>5.3 ± 1.6</td>
</tr>
<tr>
<td>AP 90 [mm]</td>
<td>9.1 ± 2.1</td>
<td>4.2 ± 1.3</td>
</tr>
<tr>
<td>IE 30 [°]</td>
<td>27.6 ± 4.8</td>
<td>21.5 ± 5.8</td>
</tr>
<tr>
<td>IE 90 [°]</td>
<td>28.3 ± 3.9</td>
<td>24.2 ± 4.4</td>
</tr>
</tbody>
</table>

More interesting results have been obtained with the analysis of pivot-shift test: coupled peaks in AP translation, at 25.0±1.8° of flexion, are reduced from -11.3±4.7mm to -3.1±3.1mm (p<0.01) after reconstruction as also in IE rotation are reduced from 10.8±4.7° to 2.6±4.9° (p<0.01) after surgery. The analysis of
the area highlighted a huge recovery of the dynamic stability of the joint, from 211.5\text{mm} * \text{deg} to 57.3\text{mm} * \text{deg} (p<0.01) (Fig. 1).

**Discussion:** The navigation protocol, applied to anatomical DB ACL reconstruction, allowed a quantitative evaluation of knee global kinematics before and after surgery: all ACL-deficient knees showed a positive pivot-shift test before the surgery with huge value in the subluxation of the tibia; anatomical DB seems to eliminate both static anterior/posterior instability (Lachman test) and to control pivot-shift (subluxation of the lateral femoral condyle) reducing tibial translation and controlling tibial rotation.

**References**
Description And Clinical Validation Of A Navigation System For Intra-operative Evaluation Of Accurate Placement Of Bone Tunnels In Reconstruction Of The Anterior Cruciate Ligament

Bhattcharyya M, Gerber B

Department Of Orthopedic, University Hospital Lewisham, London, UK

mayukhbhattcharyya@hotmail.com

Introduction: Rupture of the anterior cruciate ligament (ACL) is one of the most frequent orthopedic procedures performed in the younger adult knee with keen interest on sporting activities. During ACL reconstructive procedure, the exact placement of drilled tunnels influence the outcome of surgery such as range of motion, knee joint stability, reaction of the synovium in the knee, pain, impingement and potential graft failure. 70 % of ACL reconstructions are also carried out by orthopedic surgeons, who perform limited number of procedures in a year with or without arthroscopy [1]. Moreover, arthroscopy does not allow the surgeon to gain a complete 3D view of important anatomical structures, particularly in the antero-posterior direction. Where as computer-assisted navigation systems should allow assessment topographic anatomy with correct anatomical placement of the tunnels [2]. As the replacement of the ruptured Anterior Cruciate Ligament (ACL) of the knee is a biomechanically difficult task, we have used Orthopilot software to achieve accurate and reproducible placement of the tibial bone tunnel, for open ACL reconstruction. In this study, we describe our experience of using the orthopilot software for navigation of the ACL graft implant during our learning curve. The preciseness of the tibial tunnel placement was evaluated, and the advantages of this navigation system for open technique ACL reconstruction are discussed after 2 years of clinical follow up.
Anterior and Posterior Cruciate Ligament Replacement

Materials and Methods: We performed 49 consecutive ACL reconstruction procedures in our hospital. Patients were sequentially assigned a standard single bundle ACL reconstruction with lateral third of the patellar ligament with a lateral incision technique. In all ACL reconstruction procedures orthopilot navigation system was performed. The patients who had undergone ACL reconstruction using this system were evaluated regarding the positioning of the tibial tunnel against Blumensaat’s line using XR and the route of the graft by magnetic resonance imaging (MRI).

Results: Kinematic navigation enables us to measure anteroposterior and rotational knee stability, isometry, impingement and the angles of bone tunnel placement. At the 2 year follow-up, maximally extended lateral knee X-p revealed that the anterior edge of the tibial tunnel and Blumensaat’s line were almost aligned and that roof impingement was avoided; the T2-weighted MR images showed that the graft was placed close to and parallel to the intercondylar roof in all the knees. The ratio of the distance between Blumensaat’s line and the anterior edge of the tibial tunnel at the level of the tibial plateau to the anteroposterior width in fully extended true lateral radiographs was 2.3% +/- 2.4%.

Discussion: The computer-assisted navigation system improves accuracy and decreases dispersion of the tibial tunnel placement against Blumensaat’s line in single-bundle ACL reconstruction. Computer assisted surgery allows the reconstruction procedure more reliable, eliminating the problem of skeletal variation among patients. Although, during operation, the planning of the insertion points and accurate drilling of the transosseous tunnels is difficult with the help of the jig. The correct placement of the graft, especially the isometry of the tibial and femoral insertion points, is successfully achieved with the orthopilot software for the navigation developed for use of anterior cruciate ligament (ACL) reconstruction. It is a user-friendly navigation system for intraoperative acquisitions of anatomical and kinematic data. It performs real-time quantitative evaluation of knee laxity at any degree of flexion and allows comparison of pre-operative and post-operative knee laxity and surgical documentation. The system also helped to establish the reliability of a navigation system for femoral tunnel placement in the open single-bundle anterior cruciate ligament (ACL) reconstruction. Guidewires were inserted to the center of the anterolateral tibial and posterolateral femoral tunnels in the knees using an image-free navigation system allowed anatomical placement of the graft as evident on MRI. The relative position of the guidewires in reference to the height and depth of the lateral condyle was determined by the navigation.
system. It provided surgeons with information to determine the anatomical tunnel location in open single-bundle ACL reconstruction. The system identifies the correct insertion points of the graft. Furthermore, it allows testing the isometry of these points before drilling of the femoral and tibial tunnel, and guides the drilling itself. Kinematic based navigation in ACL surgery provides a tool for recording outcomes in terms of laxity without a necessity to use further examination methods in the recent updated version of the software. We did not require performing any secondary procedure such as notchplasty and finding no evidence of graft laxity at 2 years follow up. However, we found longer operative time during our learning curve. Three patients complained of scar tenderness at additional fixation of navigation probes to the femur and five patients at tibia. Further study should be considered in the context of long-term benefits for the patient with keen interest on sports.

References
Navigated ACL Replacement Achieves Better Isometry Than Conventional Procedures

VON RECUM J¹, WEISSER G², SEITZ A¹, WENTZENSEN A¹, CLAES L², DÜRSELEN L²

¹ Bg-Trauma Center Ludwigshafen, University Of Heidelberg, Germany
² Institute Of Orthopaedic Research And Biomechanics, University Of Ulm, Germany

von.recum@arcor.de

Introduction: The replacement of the anterior cruciate ligament (ACL) by a tendon graft is the Golden Standard in surgical treatment of ACL insufficiency. One important target parameter of ACL surgery is isometry of the graft insertion points. Isometry is desirable to avoid excessive graft stress during extension-flexion movements of the knee joint. To achieve this, conventional procedures use manual drill guides assuming that the optimum tunnel placement is located at a constant distance relative to anatomical landmarks. This takes the individual anatomy of a patient only little into account. However, navigated procedures allow testing a pair of insertion points for isometry prior to bone tunnel drilling. This permits the selection of graft insertion points more individually. The hypothesis of the current in vitro study was that navigated ACL replacement leads to better isometry and thus to less graft force variation of a tendon graft for ACL replacement during knee joint motion compared to manual drill guides.

Materials and Methods: In 20 pairs of cadaveric knee joints (age 47-90) the ACLs were cut and subsequently replaced by a tendon transplant. 4 knees joint specimens had to be excluded due to osteopenic bone. This exclusion resulted in 16 pairs of intact joints. In one knee joint of a pair the surgical procedure was performed using conventional Arthrex drill guides. In this case the femoral drill tunnel was placed at a constant distance to the dorsal cartilage rim. The ACLs of the contralateral 16 joints were replaced using a computer navigation system (ACL Logics Koala, PRAXIM-medivision). An experienced surgeon using both procedures clinically operated both groups. Initially the areas of the natural ACL insertions and the shape of the intercondylar notch were digitized using a navigated pointer tool. Then, the system calculated an isometry map predicting
the areas of least anisometry. After digitizing the expected best insertion points on femur and tibia the knees were moved from extension to 120° flexion resulting in a prediction of the maximum length change of a virtual graft. If the maximum expected length change was larger than 2-3 mm the insertion points were slightly corrected. Finally Kirschner wires were set by a navigated drill and the bone tunnels for the tendon graft placed by cannulated drills. The double folded tendon grafts were then inserted into the knee joints and fixed in the femoral drill tunnel with a Transfix II implant. The tibial sutures of the grafts were clamped outside of the bone tunnel in a special tensioning device, which allowed the adjustment and recording of the graft force. The knee joints were mounted in a knee joint loading and motion simulator allowing for 6 degrees of freedom unconstrained knee motion. After pretensioning the grafts to 70 N in 20° flexion position the knee joints were cycled 3 times between extension and 120° flexion position while continuously recording the graft force. From the graft force-flexion angle graphs the amplitude, i.e. the difference between maximum and minimum graft force was calculated, which is a measure for the degree of isometry.

**Results:** The graft force occurring during knee flexion in case of the conventionally operated knee joints did not show an isometric behaviour (fig. 1). The graft force reached a maximum of almost 140 N in knee extension and quickly decreased to 15 N in 40 degree flexion. The graft isometry in the navigated knees was significantly better resulting in a lower peak force (90 N) in extension and in keeping a considerable graft force throughout the flexion range (minimum 40 N, fig. 1).
Discussion: To restore stability and kinematics of the knee joint, reconstruction of the ACL is mandatory. Some authors prefer the double bundle reconstruction but there is no evidence of any advantage and there are some reports of difficulties in revision surgery. In single bundle reconstruction there is a need to restore the functionality of the antero-medial ACL bundle to give support during the whole range of motion. The conventionally operated knee joints did not meet the aspired behavior of the antero-medial ACL bundle. It provided an anterior stabilizing effect only between full extension and 40 degrees of flexion. The grafts showed excessive tensile load in full extension, which could lead to irreversible postoperative graft lengthening. The consequence of low graft forces beyond 40 degrees of flexion is a lack of anterior stabilization at higher flexion angles. This was most likely due to femoral insertions located in most cases too far posterior. The navigated femoral graft insertions were placed more anterior resulting in a more isometric behavior with lower peak force in extension and more stability in flexion compared to the conventional technique. This correlates to the behavior of the antero-medial bundle, also meant to be the stabilizing ACL bundle proving the ability of the navigation technique used in this investigation to take the individual anatomy of a knee joint into account. The study confirmed our hypothesis that the navigated placement of drill tunnels provides better graft isometry compared to a conventional technique.
3d Navigation Guided Fixation Of Posterior Cruciate Ligament Avulsion Fracture

TANG N, LEE KS, NG WK, LEUNG KS

Department Of Orthopaedics And Traumatology, Prince Of Wales Hospital, Shatin, Hong Kong

ntang@ort.cuhk.edu.hk

Introduction: Posterior Cruciate Ligament (PCL) avulsion fractures are rare and many are resulting from road traffic accidents. The clinical presentation is usually posterior instability on physical examination and a bone fragment seen on x-ray. CT scan is now commonly used to better delineate the fracture margins, comminution and extent. Conservative treatment may result in non-union even in undisplaced fractures and open reduction and internal fixation through posterior approach in the popliteal fossa have been the standard treatment. However complication like popliteal artery injury has been reported with open reduction and staple fixation. With the advancement of arthroscopic techniques, arthroscopic assisted fixation of PCL avulsion fractures has increase popularity but limited to a few centers only. The fixation method of the PCL avulsion fracture mainly depends on the fracture fragment size - (A) small fragments: sutures, wires, k-wire (B) large fragments- screws. In the past, it was also common practice to use a cast as an external adjunct after open reduction and internal fixation of PCL tibial avulsion fractures. Joint stiffness was one of the serious complications of prolonged cast fixation. We introduced a new surgical approach by using 3D navigation guided screw fixation in undisplaced or minimally displaced PCL avulsion fractures with large fragment size. Also immediate weight bearing and walking was started to minimize deconditioning.

Materials and Methods: 4 cases of PCL avulsion fractures presented with acute injury were managed with this new technique. There were 3 male patients and one female patient. The age ranges from 24 to 59 years old with average age 36 years. The mechanism of injury include two road traffic accidents, one fell from 2nd floor of a double deck bus and one fell on level ground (due to frequent
Anterior and Posterior Cruciate Ligament Replacement

fall and diagnosed to suffered from acoustic neuroma). Initial treatments were temporary immobilization in long leg slab and ice therapy. High resolution CT scans were also performed to help delineate the fracture fragment orientation and size. The DICOM CT data was then input into the Stryker Leibinger Navigation System and using the 3D Spine program for pre-op planning. Two 4mm titanium cannulated screws were planned from medial and lateral tibial plateau in order to transfixing the bony fragment without penetrating the cortex. The posterior cortical penetration was especially avoided to prevent injury to the popliteal neurovascular structures. The planned data was then imported to the Stryker Leibinger 3D Spine program. During the operation, the patient’s affected limb was draped and placed on radiolucent table and patient tracker was anchored to the proximal tibial shaft. 3D fluoroscopy was then performed with the Siemens Sirmobile ISO-C 3D and the images transferred to the Stryker navigation machine. By combining the high resolution CT and intra-operative 3D fluoroscopic images, the registered coordinate of the bone was transferred from latter to the pre-op CT images. By doing this image fusion, high resolution images that provide better fracture delineation was available for navigation and this also allowed us to have a larger working volume (intra-operative 3D fluoroscopy only provided 12cm’ field of view-limited by C-arm). We then use the fused 3D images for screw position, size and length verification. By using the surface rendering function, we could remove the bone and double confirming the planned screws would not cross in their passages to the fracture fragment. Then by using the calibrated drill sleeve guide, 1.4mm guide wires were inserted from medial and lateral aiming posterior-superior direction towards the PCL avulsion fracture fragment. In all the four cases, only one passage for each of the guide wires was needed and then the screws of appropriate length were inserted. Intra-operative 3D fluoroscopy were performed again for verification of the screws’ optimal position and double checked for any cortical perforation. Post-operatively, all the patients were allowed immediate full weight bearing walking. One patient has concomitant tibial shaft fracture was treated by intramedullary nailing at the same operation. The patients were then followed up with schedule at 4, 8, 12, 24, 36 weeks post-op. Hughston’s criteria were used to assess the clinical results.

Results: The intra-operative 3D fluoroscopy confirmed that there was no cortical perforation of the screws inserted. No intra-operative complication was founded. The mean follow up for the patients was 40 weeks (24 to 60 weeks). All the fractures healed unevenfully by 8 weeks’ post-operatively. Overall, according to Hughston’s criteria, all four patients reported good result in subjective and objective assessment. For functional assessment, there were two
good results; one fair result with feeling of weakness during stairs climbing; one could not be assessed due to her acoustic neuroma was affecting her balance and undergoing treatment.

Discussion: This new navigation technique in treatment of PCL avulsion fractures is safe and good outcome is expected. It also allows early rehabilitation and prevents deconditioning. However, only those undisplaced/ minimally displace fractures with sizable fragments that could accommodate two screws should be treated with this method. The 3D spine program should be used pre-operatively for planning and studying the possibility of applying this new technique.

References
- Meyers-MH. Isolated avulsion of the tibial attachment of the posterior cruciate ligament of the knee. JBJS(Am.)1975 Jul; 57(5): 669-72
Computerized Navigation Technique In Assisting Tibial Tunnel Placement Of Arthroscopic Posterior Cruciate Ligament Reconstruction

FENG H, HONG L, WANG X, GENG X, ZHANG H

Sports Medicine Service, Beijing Jishuitan Hospital, China
zhui76@126.com

Introduction: To present the clinical application of fluoro-based navigation technique in assisting tibial tunnel placement of arthroscopic posterior cruciate ligament reconstruction and investigate its efficacy and feasibility.

Materials and Methods: The navigation system uses tibia tracker fixed into the proximal tibia of the patient and tool tracker attached with PCL tibial drill guide. With registration and calibration, the navigation system identifies and captures the infrared signals actively emitted by the two trackers. The computer can thus calculate the 3D-position of the knee joint relative to the PCL tibial drill guide and then, the virtual tibial tunnel was imposed into the interactive images formed by the intra operative C-arm images. Precisely adjust the virtual tunnel position according to the intra operative planning protocol until the ideal position achieved. The intra operative planning is as follows: in the standard AP view, the centre of outlet of the tibial tunnel should be in the midpoint between the medial and lateral posterior tibial eminence and 1.5cm distal to the articular surface. In sagittal plane, with the intact posterior wall, the tibial tunnel should be as close as the posterior proximal tibial cortex to get a maximum angulation.

Results: From August 2006 to March 2007, 15 cases of navigation assisted arthroscopic posterior cruciate ligament (PCL) reconstruction were performed. All cases were combined ligament injury. 4 cases were PCL+ACL+MCL injury, 9 cases were PCL+PLC injury and 1 case was PCL+ACL injury. Among them, 14 succeed without navigation related complications, 1 failed. The frequency of intra operative fluoroscopy reduced from 2~10 times to 2~4 times and saved
10–30 minutes. Post-operatively, all success cases received X-ray, 64-rows CT scan and MRI for evaluating the tibial tunnel placement and graft. For the position of tibial outlet, all cases located in the footprint of posterior cruciate ligament. The average angulation between tunnel and graft was 123.3° (from 122° to 125°), all cases shows close spatial relationship with posterior proximal tibial cortex with the distance less than 2mm, intact posterior wall in 10 cases and slightly broken in 4 cases.

**Discussion:** With high accuracy and time-saving features, fluoro-based navigation system is a feasible technique in assisting tibial tunnel placement in arthroscopic PCL reconstruction surgery.

Fig.1  Frontal view of the invented tibial tunnel in the surgical protocol (Left) and virtual tunnel position show in the intra operative C-arm image formed by the navigation system.

Fig.2  Lateral view of the invented tibial tunnel in the surgical protocol (Left) and virtual tunnel position show in the intra operative C-arm image formed by the navigation system.

Fig.3  The post operative MRI show the angulation between the tibial tunnel and the PCL graft is 122°, reduce the “killer turn”.

Fig.4  The tibial tunnel outlet is located close to the PCL insertion area anatomically with intact posterior wall shown in 3D-CT scan post operatively.

Fig.5  The intact posterior wall of the tibial tunnel and slightly broken posterior wall shown in 3D-CT scan post operatively. It means that the tibial tunnel position is close as the posterior proximal tibial cortex to get a maximum angulation.
Measurement Of The Antero-posterior And Rotational Knee Laxity During ACL Replacement By A Navigation System

JENNY JY, CIOBANU E, BOERI C

Orthopaedic Department, University Hospital, Strasbourg, France

jean-yves.jenny@chru-strasbourg.fr

Introduction: Antero-posterior and rotational laxity are responsible for the knee functional instability after ACL rupture. The amount of anterior laxity is a diagnostic criterion, and might be a prognostic factor. Appropriate correction of antero-posterior and rotational laxity are the major goals of ACL replacement. The measurement of antero-posterior laxity by instrumental or X-ray techniques are accepted techniques of evaluation. However, the measurement of rotational instability is not commonly performed, except for experimental studies. Navigation systems might help the evaluation of this rotational instability after ACL rupture in a routine clinical situation.

Materials and Methods: We routinely use a non image based navigation system (OrthoPilot™, Aesculap, FRG) during ACL replacement. 20 cases of arthroscopic assisted ACL replacement with a bone-patellar tendon bone graft have been analyzed. The anterior laxity was measured pre-operatively by dynamic X-rays at 25° of knee flexion. Intra-operative navigation was performed according to the manufacturer’s recommendation. The anterior and rotational laxity at 25° of knee flexion were measured under maximal manual traction before and after ACL replacement. The anterior laxity was repeatedly measured post-operatively by dynamic X-rays at 25° of knee flexion. The pre- and post-operative X-ray and navigated measurements of the anterior laxity on the same patient were compared with a paired Student t-test and a Spearman correlation test at a 5% level of significance. The pre- and post-operative navigated measurements of the rotational laxity were recorded.

Results: Mean pre-operative anterior laxity measured by stress X-rays was 9.4 mm (SD 4.2 mm). Mean pre-replacement anterior laxity measured by the navigation system was 8.7 mm (SD 4.3 mm). Mean pre-replacement rotational
laxity measured by the navigation system was 7.5 degrees of external rotation (SD 3.9 degrees of external rotation).
Mean post-replacement anterior laxity measured by the navigation system was 3.2 mm (SD 1.5 mm). Mean post-replacement rotational laxity measured by the navigation system was 3.6 degrees of external rotation (SD 2.0 degrees of external rotation). Mean post-operative anterior laxity measured by stress X-rays was 4.1 mm (SD 2.4 mm).
Both antero-posterior and rotational laxity were significantly decreased after ACL replacement. There was a significant difference between either pre-operative or post-operative navigated and radiographic measurements. However, this difference was less than 2 mm in most of the cases, and then considered as clinically irrelevant. There was a significant correlation between either pre-operative or post-operative navigated and radiographic measurements.

Discussion: The navigation system used allowed us measuring anterior and rotational laxity during ACL replacement. The pre- and post-operative navigated measurement of the anterior laxity were significantly different from the pre- and post-operative stress X-rays, but were significantly correlated, and can therefore be considered as reliable. The intra-operative information about the correction of the anterior laxity might be relevant to control the quality of the procedure, and improve its reproducibility. Information about rotational laxity may be helpful, but its exact significance must be more precisely defined. The navigation system used allows an accurate and reliable measurement of the anterior laxity during ACL replacement, and also allows assessing the rotational knee laxity.
Malposition of components of total hip arthroplasty might increase the risk of dislocation, reduce range of motion and may cause long-term wear. Navigation tools should play a major role, by offering three-dimensional information in real time concerning pelvic orientation during surgery. The image-free hip navigation systems use the frontal pelvic plane (also called the McKibbin or Lewinnek plane), directly by digitizing the anterosuperior iliac spines and the pubic tubercles, as part of the reference system. However, there is significant anatomic variation of the frontal pelvic plane in the population. This is one reason why the landmark-based navigation concept using the frontal pelvic plane has not yet been clinically validated. To evaluate the validity of frontal pelvic plane, this prospective study reports only comparison between the intra-operative cup anteversion, as displayed by the image-free navigation system, and the post-operative acetabular cup anteversion, as measured on reconstructed computed tomography in 12 primary total hip arthroplasty. There were 4 females and 8 males. Mean average age was 62.1 years (29 to 82 years) and mean body mass index was 23.3 (22.0 to 31.1). All patients underwent image-free navigation assisted total hip arthroplasty using the Orthopilot® navigation system. The patients were first positioned in a supine with registration of frontal pelvic plane by percutaneous palpation and then lateral positioned on a operative table with sterile drapping. The acetabular components and femoral stems were cementless. All operation were performed through an posterolateral approach by one surgeon and all patients underwent postoperative reconstructed
computed tomography using same protocol. Data were collected with display by image-free hip navigation system and axial and planar reconstructed computed tomography and analyzed by two blinded observers. The standard definitions of cup anteversion in anatomic in axial plane and the operative in sagittal plane referentials of Murray were applied on reconstructed computed tomography. The average anteversion of acetabular cup displayed by navigation system were 28.7 degrees ± 7.4 degrees. The anatomic anteversion in axial reconstructed tomography were 28.0 degrees ± 11.3 and the operative anteversion in planar reconstructed tomography were 30.2 degrees ± 9.3. The mean overall differences of anteversion, as displayed by the image-free navigation system were 7.1degrees ± 4.4 for anatomic anteversion and 3.08 degrees ± 2.5 for operative anteversion on reconstructed computed tomography respectively. Despite anatomic definition, the frontal pelvic plane is assumed to be parallel to a horizontal plane in the supine position, there are differences (minimum 1.0 degree to maximum 11.5 degrees) between the angle of anatomic and operative anteversion on reconstructed computed tomography comparing the digitized plane to the frontal plane as the reference system of hip navigation total hip arthroplasty. With image-free navigation total hip arthroplasty, anatomic plane landmarks must be acquired intraoperatively in order to define the frontal pelvic plane. This step could potentially introduce a significant error for navigation. Variations in anteversion guided by frontal pelvic plane when navigating the acetabular cup would suggest that this plane is not reliable references relying on a more kinematic approach of image-free navigation total hip arthroplasty.
The Interrelationship Among Different Reference Coordinate Systems Of The Pelvis - A Computer Assisted Anatomical Study

TANNAST M¹, RÖTHLISBERGER M¹, GATHMANN S¹, STEPPACHER SD³, MURPHY SB², LANGLOTZ F³, SIEBENROCK KA¹

¹ Department Of Orthopaedic Surgery, Inselspital, University Of Bern, Switzerland
² Center For Computer Assisted And Reconstructive Surgery, New England Baptist Hospital, Tufts University, Boston, MA, USA
³ MEM Research Center, ISTB, University of Bern, Switzerland

moritz.tannast@insel.ch

Introduction: Knowledge of individual pelvic tilt is crucial for interpretation of spinopelvic balance and thus for interpretation of the prosthetic cup orientation in navigated total hip arthroplasty (THA) and computer-assisted range of motion considerations of the native and the prosthetic hip. Various reference coordinate systems (CS) can be found in literature. Although the anterior pelvic plane (APP) has been established as the CS of choice in surgical navigation, other references might be of potential usefulness as could be proven e.g. in coxometry¹ based on conventional radiography or for computer-assisted kinematical studies of the hip². Some of these alternative reference CS have already found their place in computer assisted surgery because of their better accessibility during surgery³. Nevertheless, no study exists that compares the interrelation among these CSs.

The aim of this computer-assisted anatomical study was (1) to compare the relationship among five pelvic CS described in literature, (2) determine the inter-/interobserver variability in determination of the anatomical landmarks for each CS, and (3) to calculate the influence of the individual reference CS on the prosthetic cup orientation.

Materials and Methods: The following reference CS were investigated (Figure): (a) the APP constructed by both anterior superior iliac spines (ASIS)
and the pubic tubercles, (b) pelvic inclination defined by a line connecting the upper border of the symphysis pubis and the sacral promontory (angle alpha), (c) pelvic incidence defined by the endplate of S1 (angle beta), (d) the notch-tuberositas line constructed by the sciatic notch and the ischial tuberosity (angle gamma), and (e) the transverse pelvic plane through both superior iliac spines and one of the ASIS (angle delta).

For investigation, the pelvic computed tomography (CT) scans of 100 consecutive patients undergoing CT-based THA were analyzed. No patient suffered from a relevant pelvic pathomorphology. All CTs were blinded, randomized and independently analyzed by two observers at two separate occasions. Three-dimensional pelvic models were created of all patients with a semiautomatic segmentation technique. Then, the four landmarks of the APP were digitized. The pelvis was then automatically oriented in a strong lateral view relative to the anterior pelvic plane which served as the gold standard reference CS. On a sagittal median pelvic cut, the above mentioned landmarks for the remaining reference CSs were captured and the relation to the anterior pelvic plane calculated. Inter- and intraobserver differences were calculated using the intraclass correlation coefficient (ICC). The validity of a CS was defined by a high reproducibility/reliability, a low standard deviation and a narrow range when measured relative to the anterior pelvic plane.

The influence of the choice of the navigation system on the resulting cup orientation was calculated exemplary for a cup orientation of 40° of radiographic inclination and 15° of radiographic anteversion using previously described nomograms.
**Results:** The interrelationship of the four evaluated references CS relative to the anterior pelvic plane is shown in Table 1. All angles had very good intraobserver reproducibility with ICCs > 0.8. A very good interobserver reliability was found for pelvic inclination and incidence while the notch-tuberositas line and the transverse pelvic plane had a fair correlation. The standard deviation was significantly larger for angle beta in comparison to the remaining CSs (p < 0.001). The lowest range was found for angle gamma, followed by angle delta and alpha. Applying different CSs to the above mentioned standard cup orientation resulted in an anteversion error ranging up to 23.8° for angle alpha as reference CS, 39.2° for angle beta, 13.4° for angle gamma, and 16.4 for angle delta.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Angle relative to the APP [°]</th>
<th>Intraobserver ICC</th>
<th>Interobserver ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha (pelvic inclination)</td>
<td>31.8 ± 4.8 (15.6 - 44.7)</td>
<td>0.95</td>
<td>0.81</td>
</tr>
<tr>
<td>Beta (pelvic incidence)</td>
<td>48.5 ± 9.3 (23.8 - 71.2)</td>
<td>0.95</td>
<td>0.83</td>
</tr>
<tr>
<td>Gamma (Notch-tuberosity line)</td>
<td>77.9° ± 3.8 (69.2 - 85.6)</td>
<td>0.89</td>
<td>0.43</td>
</tr>
<tr>
<td>Delta (Transverse pelvic plane)</td>
<td>78.4 ± 3.9 (67.9 - 88.2)</td>
<td>0.92</td>
<td>0.27</td>
</tr>
</tbody>
</table>

**Discussion:** Anatomical referencing of angles for various indications in pelvic and hip surgery is crucial. Although considered the gold standard, the APP is not suitable for some indications. This study represents an analysis of anatomical relations of alternative reference coordinate systems. The closest anatomical relationship to the anterior pelvic plane with the lowest standard deviation and the narrowest range can be found for the notch-tuberositas line. Unfortunately, this reference was subject to a considerable interobserver error. The CS with the lowest validity was the pelvic incidence which showed a large range together with a fair interobserver reliability. This CS could even result in a retroverted cup if a default orientation of 15° anteversion and 40° inclination relative to the APP was chosen.

Each of the CSs has advantages and disadvantages. Pelvic inclination can easily be seen on a lateral radiograph where the anterior pelvic plane is distorted and sometimes difficult to identify. Its references for pelvic tilt lie in a median line and are therefore relatively inert to rotation. The transverse pelvic plane allows for anatomical referencing even in the lateral decubitus position and is therefore an attractive alternative. Pelvic incidence is subject to considerable errors when degenerative changes of the lumbosacral spine are present. In summary, the APP should be used as reference CS whenever possible. If not applicable, pelvic inclination is an attractive alternative. The notch-tuberosity line and transverse pelvic plane are recommended if no other CS can be used.
References


Surface-based Vs. Landmark-based Determination Of The Mid-sagittal Plane For Surgery Planning In THR


1 Helmholtz Institute For Biomedical Engineering, RWTH Aachen University, Germany
2 Dept. Of Orthopaedic And Trauma Surgery, University Hospital Bonn, Germany
3 Surgitaix AG, Aachen, Germany

fieten@hia.rwth-aachen.de

Introduction: In total hip replacement (THR) knowledge of the mid-sagittal plane is crucial for cup navigation. The orientation of the cup can be measured with respect to the mid-sagittal plane and the so-called anterior pelvic plane (APP), and safe zones for such defined anteversion and inclination angles have been suggested by Lewinnek et al. [1]. Anteversion and inclination planning has been introduced into clinical practice based on Lewinnek’s recommendation. The position of the cup can be planned by taking into account biomechanical models requiring standardized coordinate systems. The mid-sagittal plane is an excellent reference for the patient-specific definition of standardized coordinate systems. Furthermore, the mid-sagittal plane can be used to generate templates by mirroring healthy structures. The importance of anatomic referencing has been studied by Tannast et al. [2].

A popular approach for mid-sagittal plane computation is based on the selection of anatomical landmarks located symmetrically to it, namely both anterior superior iliac spines (ASIS). However, the manual selection of landmarks is a tedious, subjective, and error-prone task. In order to overcome this drawback, we suggested surface-based mid-sagittal plane computation, and we developed a novel iterative closest point (ICP) variant for the iterative refinement of reflection parameters [3]. In this study the results of landmark-based and surface-based determination of the mid-sagittal plane using this ICP variant are compared with each other.
Materials and Methods: For the surface-based determination of the mid-sagittal plane the reflection which best matches homologous areas is sought iteratively. In contrast to the standard ICP, at each iteration the best reflection (in the least-squares sense) instead of the best rigid transform is calculated as a closed-form solution to the problem of matching paired points using a reflection, and new point pairs are generated. In a previous study [3] direct optimization in the 3D space of reflection parameters gave better results than an indirect method, where after an initial default reflection and subsequent optimization in the 6D space of rigid transform parameters the cumulative matching transform was approximated by a reflection. However, the same anatomical regions were used for optimization and for evaluation, whereas in THR the acetabular areas are most relevant for evaluation and not appropriate for optimization. As the optimal symmetry plane depends on the anatomical area, to obtain a reliable estimate of the mid-sagittal plane for the acetabular areas, it is important to use anatomical structures whose optimal symmetry planes are similar for optimization. For evaluation, matching accuracy with respect to a certain area was assessed by two parameters, the number of points with symmetrical closest point relation and the mean distance between those points after mirroring. A high number of points with symmetrical closest point relation and a small mean distance between those points after mirroring indicate high accuracies. In order to select pelvic structures with optimal symmetry planes similar to those of the acetabular areas, structures which could accurately be matched after reflection optimization based on the acetabular areas were identified. It was assumed that reflection optimization based on the identified structures would in turn allow for an accurate matching of the acetabular areas. It was concluded that the areas around the ASIS have optimal symmetry planes similar to those of the acetabular areas. Therefore, areas around the ASIS were used for surface-based mid-sagittal plane calculation.

Experiments on 12 CT datasets of human pelvises (6 male/6 female, voxel sizes between 0.6 and 1.0 mm) were performed. In the segmentation process the pelvises had been separated semi-automatically from the femurs to allow for the extraction of the complete acetabular surface area.

Anatomical landmarks, i.e. both left and right ASIS, were selected by 4 users (2 engineers/2 surgeons) for landmark-based mid-sagittal plane computation. The associated mirror planes were displayed to the users allowing them to refine their landmark selections.

Results: The surgeons needed on average 18.2 s for the selection of the anatomical landmarks (SD: 7.9 s), and the engineers needed on average 41.2 s (SD: 18.7 s). Computation times for the landmark-based method were negligible,
and computation times for the surface-based method were approximately 1 s. The surface-based method led on average to 13% more points with symmetrical closest point relation when compared with the landmark-based method performed by the engineers and to 9% more points when compared with the landmark-based method performed by the surgeons. Moreover, on average the surface-based method led to smaller distances between those points (1.11 voxel lengths) when compared with the landmark-based method performed by the surgeons (1.14 voxel lengths) and by the engineers (1.17 voxel lengths).

Discussion: Surface-based mid-sagittal plane computation can yield better results than landmark-based computation performed both by engineers and surgeons. In cases where key landmarks are hard to identify, surface-based mid-sagittal plane computation might also improve time-efficiency. The use of ultrasound-based surface information potentially will provide an efficient approach for clinical application and will be further investigated.

ACKNOWLEDGMENT: This work has been funded in parts by the German Ministry for Education and Research (BMBF) in the framework of the OrthoMIT project under grant No. BMBF 01EQQ0402/ BMBF 01EQQ0424.

References
matic extraction of the mid-sagittal plane using an ICP variant”, Proc. SPIE Medi-
Evaluation Of Intraoperative Pelvic Positioning Using Software-based Computed Tomography/radiography Matching

CHOW JC, ECKMAN K, JARAMAZ B, MURPHY SB

1 Center For Computer Assisted And Reconstructive Surgery, New England Baptist Hospital, Boston, MA, USA
2 The Robotics Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
3 Institute For Computer-assisted Orthopaedic Surgery, The Western Pennsylvania Hospital, Pittsburgh, PA, USA

jchow1@gmail.com

Introduction: Acetabular component malpositioning can lead to accelerated wear, wear induced osteolysis, instability, impingement and early revision for any of these problems. Malposition of the pelvis at the time of acetabular component insertion can contribute to malpositioning of the acetabular component. This study measures the variation in intraoperative positioning of the pelvis on the operating table during surgery by matching intraoperative radiographs with pre-operative computed tomograms (CT) using 2D-3D matching.

Materials and Methods: This randomized, prospective study was comprised of 45 patients who had received a THA from a single surgeon. According to our standard clinical treatment protocol, each patient had a pre-operative CT scan for CT-based surgical navigation of the hip arthroplasty and each patient had an intraoperative radiograph taken to assess component positioning. All THAs were performed in the lateral decubitus position on a radiolucent pegboard positioning device. Each patient’s intraoperative pelvic radiograph was taken after acetabular component and trial femoral component insertion with the leg placed in a neutral position on the operating table and with the x-ray plate aligned squarely with the operating table. The orientation of the pelvis on the operating table was calculated by comparing the intraoperative 2D projection to
the 3D CT dataset using software that can perform 2D-3D matching (Xalign). This software has been validated previously. By matching the 3D CT dataset to the magnification and orientation of the plain radiograph, the position of the anterior pelvic plane relative to the operating table could be calculated. These data were then plotted and descriptive statistics were performed.

**Results:** The mean pelvic tilt (rotation around the medial-lateral axis) was 6.84 degrees of anterior pelvic tilt (lordosis) with a standard deviation of 7.95 degrees and a range from 27.24 degrees of lordosis to 4.96 degrees of kyphosis. The mean pelvic obliquity (rotation around the longitudinal axis) was 2.89 degrees anterior from neutral with a standard deviation of 9.44 degrees and a range from 29.36 anterior to 16.59 posterior from neutral. The mean pelvic rotation (rotation around the anterior-posterior axis) was 2.56 degrees cephalad, with a standard deviation of 4.10 degrees and a range from 10.88 degrees cephalad to 5.97 degrees caudad.

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>standard deviation</th>
<th>largest value</th>
<th>smallest value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pelvic tilt</td>
<td>6.84°</td>
<td>7.95°</td>
<td>27.24°</td>
<td>-4.96°</td>
</tr>
<tr>
<td>pelvic obliquity</td>
<td>2.89°</td>
<td>9.44°</td>
<td>29.36°</td>
<td>-16.59°</td>
</tr>
<tr>
<td>pelvic rotation</td>
<td>2.56°</td>
<td>4.10°</td>
<td>10.88°</td>
<td>-5.97°</td>
</tr>
</tbody>
</table>

**Discussion:** This study shows a high variability of intraoperative pelvic positioning in the clinical setting using accurate measurement tools. The greatest variation was in pelvic obliquity or rotation around the longitudinal axis which has the greatest influence on anteversion/retroversion of the acetabular component. Since all of our intraoperative radiographs were taken with the leg in a neutral position, it is likely that the pelvis is even more greatly malpositioned at the time of acetabular component insertion, when forces applied by retractors or upon the leg may be greater. Additionally, the orientation in the remaining two planes is also highly variable. These data suggest that traditional surgical
alignment instruments for acetabular component insertion have the potential to be extremely misleading in surgery. Improved methods of assessing pelvic position during surgery, such as navigation, improved mechanical instruments, or intraoperative radiographs may increase the likelihood of placing the acetabular component in an acceptable position during hip arthroplasty.

References
The Orientation Of The Native Acetabulum: A Prospective 300 Cases CT-based Study

BLENDEA S¹, TROCAZ J², MERLOZ P³

¹ Centre Hospitalier Oloron Ste Marie, France
² Timc, Gmcao, Grenoble, France
³ Centre Hospitalier Universitaire Grenoble, France

soblend@yahoo.fr

Introduction: Optimal cup placement during total hip arthroplasty is a controversial subject. The future developments of hip navigation depend today on finding guidelines for the accurate cup placement. The interpretation of the rich classic literature data on this subject is difficult because of the variability of the methods. Moreover, most of these studies use radiographic measurements of questionable accuracy. Conventional placement of the acetabular component, using mechanical guiding tools was proven inaccurate [1]. Recent studies [2,3] suggest the use of anatomic acetabular landmarks for cup positioning. These authors found very small dislocation rates when taking in account the pelvic and acetabular anatomy. There is few data in the literature concerning the normal values of orientation of the native acetabulum [4,5,6]. The purpose of the present study is to accurately quantify the anatomic acetabular anteversion and abduction, independent of the pelvic orientation.

Materials and Methods: The initial studied population contained 200 patients who needed abdominal CT scans for non orthopaedic pathologies. The authors idea was to use the pelvic series for anatomic acetabular and pelvic measurements. A specially designed research software (Cotyle Evaluator-Praxim, La Tronche) was used to segment the data and analyze the acetabular orientation. This software has been previously validated [8]. It uses an anatomic reference system based on the anterior pelvic plane [9]. The measurements are independent of the pelvic orientation. 50 CT’s were excluded for acquisition errors or for hip arthritis. Finally, 150 CT scans containing 300 acetabulums were prospectively analyzed. The group included 67 females and 83 males, ranging from 18 years to 96 years of age. The acetabular orientation was expressed in
terms of abduction and anteversion. The statistical analysis included descriptive tools, Shapiro test for normality, linear regression test and comparative tests.

Results: The mean (± STDV) acetabular anatomic abduction was 43° ± 5 and the values ranged from 24° to 61°. The mean anteversion was 26° ± 7 (range 4° to 44°). The distribution respect a normal law (fig. 1), according to the Shapiro test. There was no significant difference (p> 0.5) between the right and left acetabular orientation.

The gender analysis showed significant differences for the acetabular orientation, between male and female subjects. The mean female abduction was 44° compared to 40° for the male group. The 4° difference was statistically significant. The female acetabular anteversion was also 2.5° higher than the male group (27° vs 25°). The authors found a significant correlation between abduction and anteversion values (p< 0.001). The abduction correlated with patients age (p< 0.01).

Finally there was a negative correlation between abduction and pelvic tilt angle (p< 0.0001).

Discussion: At our knowledge the present study is the first to describe the native acetabular orientation in a prospective study, based on accurate anatomic CT measurements, taking in account the pelvic orientation. In a recent CT study [7] the authors measured anteversion on the transverse slices and abduction on the CT topogram. However they didn’t really took in account the pelvic tilt. It is interesting to observe the important range of values for both abduction and anteversion.

Further work need to be done to evaluate the dislocation risk when placing the cup close to the patient’s native acetabular orientation. The evolution of the hip navigation could also be influenced.
References


Imageless Navigation for Acetabular Cup Placement: Pelvic-Planes and / or Transverse Acetabular Ligament?

KALTEIS T, SENDTNER E, GRIFKA J, RENKAWITZ T

Department of Orthopaedic Surgery, Regensburg University, Germany

thomas.kalteis@klinik.uni-regensburg.de

Introduction: In order to prevent malpositioning of acetabular cup in free-hand total hip arthroplasty (THA) the Transverse Acetabular Ligament (TAL) is often considered to be a good anatomical orientation for a patient specific alignment of the acetabular component. In conjunction with the posterior labrum, TAL forms a plane which represents the individual true inlet plane of the acetabulum.

Recent developments in computer assisted navigation for THA use this concept to provide an alternative workflow for acetabular cup positioning in imageless navigation in opposition to the traditional Pelvic-Planes-concept. However, no study has evaluated the reliability and accuracy of TAL-concept in navigated THA so far.

In a clinical setting following questions should be addressed: 1) Measurement of individual true inlet planes of the acetabulum in relation to pelvic planes. 2) Accuracy and reliability of intraoperative registration of TAL in imageless navigation. 3) Effect of an individual, TAL-based orientation of acetabular cup on mechanical impingement and range-of-motion (ROM).

Materials and Methods: 40 patients suffering from primary osteoarthritis of the hip were enrolled prospectively in this clinical evaluation. All patients underwent minimal-invasive THA using an imageless navigation system (Hip 5.0 unlimited, BrainLAB / DePuy). This software (release October 2007) offers three optional workflows for navigation of the acetabular cup: The traditional Pelvic-Planes-workflow, the new TAL-only-workflow, the Pelvic-Planes-and TAL-workflow. The latter was used to measure the true inlet planes of the acetabulum in relation to the pelvic-planes intraoperatively. In all patients, registration of TAL was performed by two blinded orthopaedic surgeons three
times each. The means of those measurements were taken to define the true inlet plane of the acetabulum. All measurements were used to calculate the intra- and inter-observer reliability of TAL-registration. Postoperatively, computed tomography scans were performed for all patients and the accuracy of the intraoperative registration was evaluated (MeVis, Bremen, Germany).

The range-of-motion of the hip replacement was analyzed for a patient specific alignment of acetabular component as well as for a standard abduction of the acetabular component of 45° and a standard anteversion of 15° (prototype, Hip 5.0, BrainLAB).

**Results:** Related to TAL-concept, the mean cup abduction was 41° (±5°, 32° to 51°) and the mean anteversion was 18° (±9°, -1° to 36°). In 11 of 40 patients, the true inlet planes of the acetabulum were measured to be outside the often mentioned safe-zone (abduction 40°±10°, anteversion 15°±10°). In minimal-invasive THA, reliability of registration of TAL was poor (r=0.561, p<0.001). Acetabular cup positioning along the patient specific inlet plane of the acetabulum would have lead to an impingement in a higher number of cases then positioning the cup in an abduction of 45° and an anteversion of 15° (p<0.01).

**Discussion:** For conventional free-hand THA as well as for computer-assisted navigation in THA, the TAL-concept must be seen critically. The main advantage of the TAL-workflow is a patient specific orientation of the acetabular component. Another advantage is the abandonment of the registration of pelvic planes in navigated THA. However, compared to the traditional Pelvic-Planes-concept, there are drawbacks of the TAL-workflow too: Due to the anatomy of TAL, its identification, exposure and registration is limited especially in minimal-invasive THA. Therefore the reliability of the TAL-workflow is critical. In a serious number of patients, the true inlet plane of the acetabulum may be orientated inadequately, for example in retroversion or in a steep inclination. An extreme orientation of the individual inlet plane of the acetabulum must be considered as a possible pathology for the development of osteoarthritis. An alignment of the acetabular cup along this individual orientation may compromise the biomechanical features of hip replacement, for example wear rates or range-of-motion.

Due to problems in registration of TAL, inter-individual deviations of the true acetabular inlet plane and due to biomechanical features that have to be respected in THA, the TAL-concept cannot replace the Pelvic-Planes-concept in computer-assisted navigation for THA.
Patellar Kinematics During Computer-assisted Total Knee Arthroplasty


1. Centre For Bioengineering Research & Education, University Of Calgary, Calgary, Canada
2. Hôpital De La Cavale Blanche Centre Hospitalier, Universitaire De Brest, Brest, France
3. Clinique Du Cèdre, Rouen, France
4. Clinique Pasteur, Royan, France
5. Praxim, Grenoble, France
6. Acceleware Inc., Calgary, Canada
7. Traitement De L’information Médicale Inserm, Brest, France

kctho@ucalgary.ca

**Introduction:** Maltracking of the patella after total knee arthroplasty (TKA) often results in complications, in particular, anterior knee pain. Each surgical step is important for patellar tracking, including component positioning, soft tissue handling and surgical technique. Identifying and correcting problems intraoperatively could decrease the rate of anterior knee pain and other patellar complications, and thus reduce or avoid revision operations. Computer-assisted surgery (CAS) can potentially benefit the patella by improving the proper positioning of femoral and tibial components and by allowing changes to the surgical plan to improve patellar tracking. To our knowledge, in vivo data regarding changes in patellar kinematics due to arthroplasty have not been reported and the specific clinical effects are unknown. The objectives of this study were to: (1) test the clinical feasibility of a CAS system designed to measure intraoperative patellar kinematics, (2) calculate the magnitudes of the pre-arthroplasty and post-arthroplasty kinematic changes from a pilot study measuring in vivo patellar kinematics and (3) establish whether arthroplasty resulted in any consistent, significant changes in patellar kinematics that could affect the surgical outcome.

**Materials and Methods:** A patellar kinematics module was incorporated into an existing CAS system for the femoral and tibial cuts (Praxim, Grenoble,
France). During surgery, a custom patellar marker array was attached securely to the anterior surface of the patella. Pre-arthroplasty kinematics were recorded before opening the joint capsule by capturing continuous kinematic data of the patella, femur and tibia as the surgeon manipulated the leg through several range-of-motion cycles. Once the surgeon planned the femoral cuts, the CAS system presented the pre-arthroplasty patellar trajectory information, allowing the surgeon to compare the original patellar trajectory to the femoral component surface, thus allowing the possibility to change the planned femoral cuts based on this information (although this was not done in the pilot study). After all cuts were made and the components inserted, the post-arthroplasty kinematics were recorded through several range-of-motion cycles.

Three experienced surgeons (ES, JLB, CdL), who routinely use the tibiofemoral CAS system, were selected to test the clinical application of the patellar system. In vivo kinematics were measured pre-arthroplasty and post-arthroplasty for 18 patients (8F/10M, 68±8yrs, 11R/7L knees, 6 resurfaced/12 non-resurfaced patellae). Posterior-stabilized LCS Complete Rotating Platform knee components (DePuy, Warsaw, IN) were used in all cases.

Kinematic data over the range-of-motion cycles were interpolated at one-degree increments of tibiofemoral flexion and averaged across the 3-7 cycles of flexion and extension at each increment. All six degrees of freedom were analyzed. We extracted the patellar data at 15°, 45°, 90°, and 120° tibiofemoral flexion and performed a repeated-measures ANOVA, followed by paired Student’s t-tests, corrected for the multiple comparisons (α = 0.05/6 = 0.008) to compare the pre-arthroplasty and post-arthroplasty results. We also calculated the absolute pre/post-arthroplasty differences, to disregard the direction of change.

**Results:** Clinical use of the patellar kinematics module by three surgeons for multiple patients with both non-resurfaced and resurfaced patellae demonstrated the feasibility of the system in vivo.

Mediolateral shift and tilt had the greatest magnitudes of absolute change due to arthroplasty (mean, 4.1 mm, 4.6°) relative to the total range throughout flexion (averaging 2.1 mm and 5.8°). Nevertheless, there was no surgical bias, i.e. changes were distributed almost equally medially and laterally (Figure 1).

There was a small, but consistent, proximal shift in the femoral and tibial joint lines (mean, 4.2 mm) to manage the larger flexion gap following posterior cruciate ligament excision. This resulted in pseudo patella baja, i.e. more distal contact of the patella on the femoral component, leading to significant changes (p<0.008) in the proximodistal and anteroposterior patellar position as well as patellar flexion due to arthroplasty.
Figure 1: Pre- and post-arthroplasty patellar trajectories (mean and standard deviations shown). Geometric data for the femurs were obtained intraoperatively by matching digitized portions of the femoral surface to a statistical model. The schematics of femoral bone and component are generic shapes.

Discussion: The visualizations provided by the CAS system, as well as an overlay, during data analysis, of the three-dimensional component geometry onto the individualized shape of the patient’s femur revealed that the femoral component was positioned proximally relative to the original femoral shape in all cases. Proximalization of the tibial joint line occurred due to reduced resection of the tibial bone rather than an extra-large tibial insert. As a result of these changes, the patella contacted the femoral component more distally (pseudo patella baja) and “rounded the corner” towards the distal condyles sooner than in the natural joint (Figure 1). Although consequences of true patella baja (i.e. a short patellar tendon) are considered greater than for pseudo patella baja, the latter can potentially lead to several postoperative implications including patellofemoral impingement in deep flexion, decreased range of motion, decreased lever arm (thus requiring greater energy expenditure), and anterior knee pain.

Changes in mediolateral shift and tilt due to arthroplasty were quite variable, with standard deviations averaging 5.0 mm and 5.6° respectively, such that the changes in some cases were substantial. Mediolateral changes may be due to a shift in the femoral groove location or excessively tight soft tissues for one of several reasons: translation or axial rotation of the femoral component; medialization or lateralization of the patellar component; or changes due to realignment of the leg, i.e. correcting varus or valgus.

A patellar CAS system could provide intraoperative awareness of patellar tracking, including the impact of changes in the tibiofemoral joint line. Patellar tracking may be improved intraoperatively by selecting different component sizes or changing the position and orientation of the components based on
visualizations and patellar trajectory information. Use of a patellar CAS system could allow patellar problems to be resolved intraoperatively, thus reducing the rate and severity of pain and complications after total knee arthroplasty and ultimately improving postoperative outcome.
Preliminary Patello-femoral Joint Navigation In Computer Assisted Total Knee Arthroplasty - An In-vitro Study

BELVEDERE C¹, LEARDINI A², ENSINI A², FELICIANGELI A², BIANCHI L², CATANI F², GIANNINI S²

¹Movement Analysis Laboratory, Istituti Ortopedici Rizzoli, Bologna, Italy
²Department Of Orthopedic Surgery, Istituti Ortopedici Rizzoli, Bologna, Italy

belvedere@ior.it

Introduction: It is well known from the literature how total knee arthroplasty (TKA) alters normal tibio-femoral joint (TFJ) and patello-femoral joint (PFJ) kinematics. After TKA, frequent abnormal patellar tracking results in PFJ disorders and frequently in failure of TKA. Particularly, normal patellar tracking is further affected by patellar component positioning in case of resurfacing. It is fundamental to assess PFJ kinematics intra-operatively in order to allow the surgeon to comprehend in advance the effects of every relevant surgical action on both TFJ, as by standard navigation, and also on PFJ. Furthermore, it would be also very helpful to monitor bone preparation and component positioning also for the patella in case of resurfacing [1]. Computer-aided surgery has recently introduced knee surgical navigation systems in TKA. These are able to monitor accurately all six degree of freedom of TFJ kinematics during all phases of TKA and to improve femoral and tibial prosthesis component positioning [2]. These have disregarded completely the patella until now. The aim of this study was to assess the feasibility in-vitro of a fully navigated TKA, i.e. including also intra-operative evaluation of three-dimensional anatomical-based patellar tracking and patellar cutting, in case of resurfacing, by a knee navigation system suitably adapted to this study aim.

Materials and Methods: Sixteen fresh-frozen amputated legs with the knee free from anatomical defects, with intact joint capsule and quadriceps tendon were analyzed using a surgical navigation system (Stryker® Knee Navigation System, Kalamazoo, MI-USA). Clusters with active markers were pinned onto the femur, tibia and patella for relevant bone tracking. The standard pointer was used for system control and landmark digitations used for anatomical reference.
frame definitions. Movement registrations, consisting of acquisitions of five manually driven knee flexions in a 0°-140° arc, were performed under condition of 100 N vertically applied at the quadriceps. Both TFJ and PFJ kinematics were analyzed using recommended [3] and recently proposed [1] anatomical and joint conventions. For the PFJ, this includes flexion, tilt, rotation and shift [1]. Standard deviation (SD) and mean values for all kinematic variables were calculated at each degree of TFJ flexion. Movement registrations were acquired and analyzed on all intact knees in order to create reference values assumed as the normality. A mean position for the most posterior point of the intact patella was also identified.

A preliminary procedure for the navigation of the patella was assessed on a single specimen implanted with a posterior-stabilized TKA (Scorpio®, Stryker Orthopaedics, Mahwah, NJ-USA), randomly selected among the sixteen. Patellar flexion, tilt, rotation and shift were measured in the intact knee and after normally navigated TKA, before (Unres.Pat.) and after (Initial Pat.Res.) conventional, i.e. not navigated, patellar resurfacing. Orientation of the patellar osteotomy and position of the most posterior point of the patellar component were identified in the patellar anatomical reference frame by digitizations with the pointer. After comparison of the kinematic variables and of the posterior point location between this latter condition and the corresponding reference mean values, the patellar component position was changed to a 5 mm more medial location and additional kinematics measurements were taken (Pat. Re-positioning). Finally, adjustments of patellar osteotomy were also performed in order to improve its anatomical alignment about the longitudinal axis, and final kinematics measurements were taken (Pat. Re-cutting).

**Results:** As for the definition of the reference normality, an intra-specimen repeatable path of motion over repetitions and a coupled path of motion throughout the flex-extension cycle were observed in intact knees, both at TFJ and at PFJ. PFJ rotations and shift had a mean standard deviation over TFJ flexion of respectively less than 1.1° and 1.0 mm over the sixteen knees. After TKA without patellar resurfacing, the data showed a correction slightly in TFJ varus and patellar tilting at about 10° more medial than the normality. After resurfacing with the conventional technique, all PFJ variables were altered. Particularly, an abnormal lateral tilt, about 15° more than the normality) and a medial translation (on average, 8mm more than the normality) were observed. Patellar osteotomy was originally with a 22° lateral tilt with respect to the relevant anatomical frontal plane (i.e. less than necessary bone removed laterally), whereas the most posterior patellar component point was 5mm more
lateral with respect to the corresponding in the intact patella. The patellar component was re-positioned and the patellar osteotomy re-aligned accordingly. The final results demonstrated restoration of the normal kinematics both for the TFJ and PFJ, i.e. within the reference normal band. In the figure, patellar tilt of the selected specimen as measured before and after every surgical action is reported and over-imposed on the normality band (yellow).

Discussion: The results here reported reveal the relevance and feasibility of navigated TKA that includes also assessments on PFJ kinematics and support for patellar bone preparation for suitable patellar component positioning in case of resurfacing. By using this additional information in in-vivo TKA, the surgeon can perform a more comprehensive assessment of the original knee kinematics. For example, by analyzing intra-operatively PFJ kinematics at the intact knee with quantitative measurements, no-resurfacing should be preferred if the original patellar tracking results nearly physiological, whereas resurfacing should be performed more selectively, as in the case of severely deforming arthritis causing patellar maltracking. Furthermore, during TKA, abnormalities at both TFJ and PFJ kinematics can be in the future corrected intra-operatively by more cautious preparation of the femoral, tibial and patellar osteotomies, in case of resurfacing, and by correct positioning of the three prosthetic components.
References


Tensioning And Gap Kinematics In Total Knee Arthroplasty - Navigated Measurements To Control Influence Of The Patella And The Posterior Cruciate Ligament

KENDOFF D1, PLASKOS C2, GRANCHI C2, LASKIN R1, PEARLE A1, MAYMAN D1

1 Hospital For Special Surgery, New York, USA
2 Praxim Medivision, Walpole, MA, USA

kendoffd@hss.edu

Introduction: Adequate ligament balance is considered to be one of the most critical factors in both cruciate retaining and substituting total knee arthroplasty (TKA). Due to a lack in current tools, however, so far to our knowledge only very limited data exists on gap kinematics with the patella in its anatomical position and with the ligaments tensed. So far most used tensioning devices did not allow for a combined application of tension with reduced soft tissues. Most mechanical tools therefore did could not include the physiologic conditions of the soft tissues intraoperatively or under laboratory conditions. The objective of this study was to quantify the effects of the patella completely reduced and the PCL on gap kinematics when constant tension is applied to the medial and lateral compartments throughout a full flexion cycle.

Materials and Methods: A new computer-controlled tensioner was used to measure the medial and lateral gaps in 10 normal knee specimens throughout a full range of motion. This tensioner allows for simultaneous application of tension to both compartments, reduce the complete soft tissues and measures the applied load in the knee joint under all flexion and extension conditions. A navigated tibial cut was performed and the gaps were measured medially and laterally using constant applied forces of 50 N, 75 N and 100 N per side. Gap data were acquired at 0 °, 30 °, 60 °, 90 ° and finally 120 ° of flexion. The test was performed with the patella everted and reduced. Secondary the the Posterior Cruciate Ligament (PCL) was dissected and measurements repeated.
Therefore the following test conditions could be performed:

A: patella reduced, PCL intact
B: patella everted, PCL intact.
C: patella reduced, PCL excised.
D: patella everted, PCL excised

All measurements were repeated three times by two observers. Statistical significance was determined between any two sets of conditions (defining the patella closed and PCL intact as neutral value) using the Paired Students T-test with a confidence interval CI of 95%.

**Results:** At 90° of flexion: (A) the mean medial gap was 1.5-2.5 mm smaller than the mean lateral gap for all scenarios and forces tested (p<0.05); (B) then evertting the patella decreased the medial and lateral gaps by 1 mm and 1.3 mm with an intact PCL, and by 1mm and 2.7mm with the PCL resected, respectively; (C) the PCL resection resulted in increased flexion gap heights of ~1-2 mm for both sides. (D) During knee flexion from 30° to 90°, the PCL tended to squeeze the medial compartment by 1-2mm (p<0.05). A force increase of 25N in this 50-100N range resulted in a mean gap increase of 0.25mm throughout the range of flexion.

**Discussion:** Measurement of gap kinematics with a computer-controlled tensioner and a completely reduced patella is feasible. This is the first time simultaneous gap measurements under controlled tension and reduced soft tissues could be performed experimentally to our knowledge. Care should be taken when interpreting gap balance and symmetry data when the patella is everted and further when the PCL is retained. We believe the clinical relevanceshould be considered in knees which are balanced with the patella everted may be post-operatively 1-3mm more lax in flexion than planned. When retaining the PCL, the surgeon should be aware of its contribution on flexion gap balance and symmetry. Further clinical studies need to improve our findings.
Comparison Of Soft Tissue Balancing Techniques In Total Knee Replacement Using Computer Navigation

Kamat YD¹, Aurakzai MK², Kalairajah Y¹, Field RE², Adhikari AR²

¹ South West London Elective Orthopaedic Centre, UK
² Epsom & St. Helier University Hospitals Nhs Trust, London, UK

Introduction: Appropriate tissue balancing is a vital element of total knee replacement (TKR) surgery. Different balancing techniques have been developed over the years but there is very little comparison between these in literature. This is because (a) different techniques were used with different prosthetic designs by different surgeons and (b) outcome measurement parameters for soft tissue balance are not well defined. The use of computer navigation in TKR has enabled precise measurement of bony alignment as well as soft tissue tension. More recently it has also allowed the surgeon to obtain kinematic analysis of the joint at the time of surgery. We aimed to compare the intra-operative outcome of two soft tissue balancing techniques in TKR with the assistance of computer navigation and kinematic graphs.

Materials and Methods: A prospective randomised study with local ethical approval was undertaken in patients who had a computer navigation assisted TKR by a single surgeon using the same design of prosthesis (TC Plus SB, Smith & Nephew Orthopaedics, UK). Patients were randomly assigned to two groups, the only difference being the technique of soft tissue balancing. Group A (Bone Referencing) involved subjective assessment of soft tissue balance with spacer blocks after making bony cuts (classical femur first technique). Medial or lateral release were made accordingly if deemed necessary. Group B (Ligament Balancing) involved objective measurement of ligament tension using a force feedback tensioner. Adjustments to bony cuts of the femur could be made depending on equalisation of soft tissue tensions after the tibial cut...
was made. Sample size calculations (statistical power 80%) showed that 38 subjects were required in each group i.e. a total of 76 TKR.

Results were assessed via measurements made at the time of the trial reduction. These were (i) total coronal laxity and (ii) deviation from a straight line within a passively obtained knee kinematics graph plotted by the computer navigation software. The operating surgeon was blinded to these measurements by turning the computer screen away.

**Results:** Total coronal laxity measurement at full extension and 30° flexion showed no difference between the techniques (p= 0.93 and 0.98 respectively). Navigation kinematics were better in group B, but not statistically significant (p= 0.19). However when the knees with greater pre-op deformity were considered separately, kinematics were seen to be significantly better in group B (p= 0.005). Tourniquet times were longer in group B, but not significant (p= 0.53). Complications were similar in both groups.

**Discussion:** Current gold standards for kinematic assessment of TKR are established by flouroscopic techniques. However these are largely restricted in sample size due to the involvement of high radiation doses. Computer navigation allows the assessment of only passive knee movements. However it can be performed for a large number of TKR. Developments in computer navigation software could make it comparable to flouroscopic knee kinematic assessment.

Both techniques of soft tissue balancing yield equally good results. The Ligament Balancing technique using objective measurement of ligament tension probably works better in cases of greater pre-op deformity. Exploring knee kinematics with computer navigation assistance can help improve TKR techniques.
Flexion Contracture Correction In Navigated Total Knee Arthroplasty

Ilyas J1, Kumar P1, Deakin AH1, Brege C1, Young D2, Picard F1

1 Department Of Orthopaedics, Golden Jubilee National Hospital, Clydebank, UK
2 Department Of Statistics And Modelling Science, University Of Strathclyde, Glasgow, UK

angela.deakin@gjnh.scot.nhs.uk

Flexion contracture is a common deformity encountered in patients requiring total knee arthroplasty (TKA) and the correction of this remains a challenge. Optimal knee function requires maximal restoration of knee extension. Both the soft tissue envelope and articular bones are involved in the knee extension lag therefore soft tissue management and additional bone resection are traditional options for flexion contracture correction. A few studies in the past have assessed the relationship between bone cuts and extension deficit by using goniometers and rulers. However using navigation for TKA enables the accurate measurement of knee flexion contracture and bone cuts.

The aim of this study was to try to establish a relationship between extension lag correction and the size of bone cuts made and the amount of soft tissue release. We also hypothesised that the post implant computer aided system measurements would not be significantly different to the extension angles measured at six weeks post-operatively in the follow-up clinic.

One hundred and four continuous TKA (98 patients) were completed by a single consultant using the OrthoPilot® (BBraun, Aesculap) navigation system and Columbus implants. Of the group, 44 were male and 54 were female. Average age was 68 (range 49-87), mean BMI was 32.86 (22.26-51.86) and mean Oxford score preoperatively was 42 (range 21-56). Data were recorded prospectively. At the preoperative assessment clinic these data included clinical flexion contracture angles and Oxford scores. Intra-operatively data were recorded using the navigation system. These included pre-implant flexion and extension angles, actual bone cuts of tibia and femur (both medial and lateral),
post-implant correction of flexion and extension angles and type of soft tissue release. At six weeks post operation, patients were seen in the follow clinic and clinical flexion contracture and Oxford score reassessed by the Arthroplasty outcome service. Seventy-four knees had preoperative flexion contracture (including neutral knees) while 30 were in hyperextension. Of the 74 knees with fixed flexion, 57 had no release, four had an intermediate medial release and 13 had an extensive medial and posterior release. Extra bone was resected from the distal femur only if balancing failed to correct the deformity.

For knees with fixed flexion (n = 70) there was a significant statistical difference between the pre and post implant extension angle (p << 0.0001) and mean Oxford score post-operatively was 28 (range15-50). There was no correlation between the thickness of bone cuts and postoperative extension lag either for the group with no release (p = 0.495) or posterior release (p = 0.516). There was also no correlation between bone cuts and preoperative angles for either type of release (p = 0.348 and p = 0.262). There was a significant difference between the preoperative extension deformity for the two soft tissue releases performed (p = 0.00019), the mean fixed flexion angles being -4.4° and -10.4° for no release and posterior release respectively. For the preoperative assessment clinic and postoperative follow up results, measurements were grouped and comparisons were made using a Pearson Chi-square test. There was no relationship between post-implant extension angle measurements (by computer) and extension angles at six weeks (by goniometer) (p=0.682). Also, there was no relationship between pre-operative measurement angles collected at the pre-assessment (by goniometer) and the pre-implant angles measured on the table (by computer) (p=0.682). We found that BMI (up to 35) and post-operative Oxford scores were significantly related to the extension levels with values of (p=0.008) and (p=0.027) respectively. Pre-operative Oxford scores, pre-operative extension, amount of bony resection and soft-tissue releases did not show any significant relationship with the post-operative extension obtained at six weeks.

Flexion contracture deformity in TKA can theoretically be solved in two ways: either by extensively releasing the soft tissue or by increasing the extension gap by cutting more bone (logically the distal femur). Appropriate soft tissue management and release in TKA is crucial in balancing the prosthesis in the coronal as well as the lateral plane. This study seems to confirm the supremacy of soft tissue management and release over bone cut resection. Cutting more or less bone could in fact lead to a poorer outcome as this will change the joint line level without having any additional beneficial effect in correcting the flexion contracture. Conversely adequate soft tissue release has corrected the flexion
contracture when needed. In conclusion, there was no correlation between bone cut resection and extension lag correction and with large extension deficits, a posterior soft tissue release and osteophytes resection was more important than bone cuts. We also found that the post implant computer aided system measurements were not related to the extension angles measured at six weeks post-operatively in the follow-up clinic. The conclusions that we draw from this are that there might be other factors that are likely to influence extension lag between the operation and the follow-up at six weeks. One of the factors that we could identify was the BMI. The extensor lag is important because it leads to a poorer knee function, as indicated by the Oxford scores. Despite most of the post-implant measurement angles showing no extensor lag, about 20% of our patients still had more than five degrees flexion contracture at six weeks.
Computer Aided Gap Balancing Improves Sagittal Stability For Cruciate-retaining Total Knee Arthroplasty - Results Of A Prospective Randomised Trial

PANG HN, YEO SJ, LO NN, CHONG HC, CHIN PL, ONG JCA

Department Of Orthopaedic Surgery, Singapore General Hospital, Singapore

Introduction: The success of total knee arthroplasty depends on restoration of limb alignment, precise implant positioning and optimal gap balancing. The advent of computer aided surgery (CAS) has improved limb alignment\(^1\) and implant positioning\(^2\). Gap balancing affects the final knee kinematics\(^3,4\) and suboptimal soft tissue balancing can lead to accelerated polyethylene wear\(^5\). Therefore, balanced and equal extension and flexion gaps are ideal\(^6\). It seems intuitive that this same accuracy that can be achieved with CAS with regards to bone cuts, may be translated with similar precision to gap balancing in TKA. As yet there is no published data on this subject. The objective of this single-blinded, randomized controlled trial was to assess the outcomes of CAS gap balancing in TKA using a soft tissue tensioning device.

Materials and Methods: 140 patients were randomized into two groups. The control group underwent conventional total knee arthroplasty with trialing of implants and no computer assistance. The CAS group underwent computer aided gap balancing with the use of a tensioning device. Outcome assessment was made at six months postoperatively by documenting the range of motion, the presence of flexion contractures, hyperextension, amount of anterior and posterior tibial translation with KT-1000 arthrometer, clinical varus/valgus stress tests, postoperative weightbearing radiological films of the knees, Knee Society Score, Oxford Knee Questionaire and SF-16 questionaire.

Results: Only one patient (1%) in the CAS group had postoperative flexion...
contracture more than 5º. There was significantly more patients (eight patients, 11%) in the control group with flexion contracture more than 5º (p=0.05). No patients in the CAS group and three patients (4%) in the control group had postoperative hyperextension more than 10º.

There was significantly more patients in the control group (seventeen patients, 24%), who demonstrated anterior tibial translation > 5mm, than the CAS group (ten patients, 14%) (p = 0.025). Ten patients (14%) from the CAS group were in the outlier groups with posterior laxity < 2mm or > 5mm. The control group displayed a more irregular distribution with significantly more patients (36% [twenty-five of seventy patients]) in the outlier groups (posterior laxity < 2mm or > 5mm) (p=0.036).

Fifty patients (71%) in the CAS group had mild medial laxity and twenty patients (29%) had moderate medial laxity. In the control group, forty-five patients (64%) had mild medial laxity while twenty-five patients (36%) had moderate medial laxity. This difference was not statistically significant with the numbers studied. For the assessment of lateral laxity, forty-eight patients (69%) in the CAS group had mild laxity and twenty-two (31%) had moderate laxity. This was not significantly different from the control group which had forty-seven patients (67%) with mild lateral laxity and twenty-three patients (33%) with moderate lateral laxity.

The CAS group was able to demonstrate significantly better limb alignment with fewer outliers (more than 3º varus/valgus) than the control group. There was no significant difference in the outcome scores and the complications.

Discussion: In our study, computer aided surgery was able to achieve more precise and accurate gap balancing and restoration of limb alignment in total knee arthroplasty.

References


Full Automatic Ultrasound Probe Calibration For The Computer Assisted Orthopaedic Surgery

CHAOUI J1, 2, 5, DARDEENNE G1, 2, 3, HAMITOUCHE C1, 2, STINDEL E1, 4, ROUX C1, 2

1 INSERM, U650, Brest, France
2 TELECOM Bretagne, Brest, France
3 Université de Bretagne Occidentale, Brest, France
4 CHU Brest, Service d’Orthopédie-Traumatologie, Brest, France
5 PRAXIM, La Tronche, Grenoble, France

jean.chaoui@telecom-bretagne.eu

Introduction: Three-dimensional freehand ultrasound imaging has found several clinical applications, such as Computer Assisted Orthopaedic Surgery CAOS, since the last decade. The CAOS systems allow the surgeon to objectively plan out critical surgical variables, and provide a 3D representation of the patient’s pathological bone which is used to enhance the visualization for the surgeon, provide image guidance and assist in planning and navigation. In consequence, the calibration is a key step of all the freehand ultrasound imaging systems.

Calibration is the procedure to calculate a two to three-dimensional transformation matrix which precisely converts 2D coordinates for objects detected in two dimensional ultrasound images to 3D spatial coordinates. This paper is devoted to present a novel concept for freehand ultrasound calibration method which is based on probe virtual movement simulation.

Most articles involving this area of research are mainly not concerned with such problems as time of procedure and clinical ability issues, and the ease to use. This method has significant advantages comparing with the prior approaches: our experiments show that the novel method can be captured fairly accurately by a large number of data points generated by only one ultrasound image using the simulation concept. Moreover, this method is fast, easy to use, and does not need user intervention, so it is totally automatic.

Materials and Methods: The idea. In the calibration procedure using a plane, the resulted ultrasound image is the same for several translations and rotations of
The probe: translating or sliding probe along plane, rotating probe about vertical axis on the plane, and for rotating probe about an axis which is contained in the plane.

The previous cases of motions produce the same lines in the same locations while moving the probe from several angles and for several steps. Therefore, we could simulate mathematically those movements. With that aim, we fix the plane and assume a virtual probe reference, we simulate the movements of the latter by applying rotations and translations as we mentioned before. We determine the range of motion for the two rotations and the two translations above-mentioned, then and register the positions of the virtual reference while applying the transformations. Six sequences of motions required for calibration must be exercised to identify the parameters. The two movements (side to side probe rotation, or raise and lower the probe to the plane) introduce modifications to the ultrasound images while applying the transformations, so to simulate them; we need also to simulate the modifications into the images. It is necessary to calculate the scale factors, in order to perform the needed modifications.

Proposed Phantom. It consists of 3 nylon wires which form a simple triangle, where the base wire represents the surface of a virtual plan, this phantom produces very well defining image for the triangle which facilitate calculation of wires intersections.

The next step is to palpate two points of each wire, which will be sufficient to obtain their equations in the space according to reflective markers on the references that are fixed to the phantom. Then, using a simple linear equations system, we can calculate easily the scale factors.

Results: In order to evaluate the new method in terms of precision and accuracy, 20 calibration matrix were obtained by repeating the procedure 20 times. A single point phantom, consisting of a small triangular groove in a thin plastic membrane, was used to perform this evaluation. The center of triangular groove was determined using optical pointer. To test the accuracy, we scanned the triangular groove from several positions, where the center was marked manually in the US images. The pixels coordinates were scaled back and transformed to the spatial 3D coordinates using the 20 calibration matrices, the 20 measurements evaluate the reproducibility of the method by measuring how well they repeatedly identified the 3D location of a point in the space. The target registration error was considered as the Euclidean distance between the two measurements and was calculated for each matrix. We also evaluate the accuracy in relation to the pixels position in the US image by segmenting the image into 4 regions.
The results of the evaluation can be seen in the following Table, the mean error varies from 0.715 mm for the top-left region of the US image, to 1.137 mm for the bottom-left region.

<table>
<thead>
<tr>
<th></th>
<th>Bottom right</th>
<th>Bottom left</th>
<th>Top right</th>
<th>Top left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (mm)</td>
<td>1.1365889</td>
<td>0.88574818</td>
<td>0.90554439</td>
<td>0.715035113</td>
</tr>
<tr>
<td>SD (mm)</td>
<td>0.3997645</td>
<td>0.43433557</td>
<td>0.36950281</td>
<td>0.349262841</td>
</tr>
<tr>
<td>Min (mm)</td>
<td>0.2727177</td>
<td>0.07067828</td>
<td>0.12210325</td>
<td>0.067544975</td>
</tr>
<tr>
<td>Max (mm)</td>
<td>1.9912364</td>
<td>1.98087028</td>
<td>1.65463535</td>
<td>1.731095417</td>
</tr>
</tbody>
</table>

**Discussion:** The proposed calibration method is evaluated by using a custom designed single point phantom. The probe movements simulation produces a uniform dataset, thus the proposed calibration algorithm always converges to the global minima. Only one US image is needed to generate 479 virtual images corresponding to 245760 data points in just one second.

A novel approach of US calibration has been presented. This approach is based on mathematical simulation instead of manual positioning of the probe avoiding user intervention. In addition to potentially reducing the calibration time, the simulation provides very wide accurate datasets using only one US image. The results of this robust and fully automated methodology have been described and compared with the traditional methods to prove that it is not only easy and fast to perform but also very accurate so it meets the requirements for the clinical use.

**References**

2.5d Ultrasound For Measuring Leg Geometry

KEPPLER P\textsuperscript{1}, SAUER V\textsuperscript{1}, BARTL C\textsuperscript{1}, KOZAK J\textsuperscript{1}, PINZUTI JB\textsuperscript{2}, LEITNER F\textsuperscript{2}, GEBHARD F\textsuperscript{1}

\textsuperscript{1} Department Of Orthopedic Traumatology, University Of Ulm, Germany
\textsuperscript{2} B. Braun Aescualp, Tuttingen, Germany

dsjaeger@web.de

Introduction: Today navigation systems are very common in TKA and HTO surgery. 2.5D ultrasound has proven to be very useful in the analysis of the leg geometry pre- and postoperatively. But the gold standard for measuring legtorsion, -axis and -length is still CT scan and long standing x-rays. Reasons why 2.5D ultrasound is not routinely used in the clinical set up is the necessity of special navigation equipment and a controversial accuracy and reproducibility of this technique. Therefore we integrated an ultrasound machine in a widespread used navigation system and evaluated accuracy and inter- and intraobserver variability. We also evaluated the learning curve to get investigator independent measuring results.

Materials and Methods: We combined an ultrasound machine (TELEMED\textsuperscript{®}) with a navigation system (Orthopilot\textsuperscript{®}). On the calibrated 5MHz ultrasound probe, we fixed active markers on a circular manner, to guarantee visibility in every position of the space. With a special developed software all osseous landmarks seen by ultrasound can be saved with the coordinates of the ultrasound picture. After saving the picture, the mode of the ultrasound probe changes and the probe becomes a pointer on the screen. This mode makes it possible to mark the osseous landmarks on the ultrasound picture immediately even under sterile conditions.

We verified the accuracy of the system with a specially designed leg model. Every measurement was repeated five times by the same investigator. The torsion of the femur, tibia and leg was measured in 2° steps from -40° to +40° and the mechanical leg axis in 1° steps from 20° varus to 20° valgus. Due to the design of the bone model, we were able to measure three femur lengths 468mm, 510mm and 533mm, three tibia lengths 296mm, 338mm and 381mm.
and 21 different leg lengths depending on the mechanical leg axis ranging from 835mm to 848mm.
The reproducibility was verified on 25 healthy volunteers with a mean age of 25 years (range 18 to 45 years). Two independent investigators measured the length and torsion of the femur, tibia and the whole leg and the mechanical leg axis at two different days.

**Results:** Accuracy measurements on the model: the maximum deviation in all 40 length measurements was 1.5mm, the maximum deviation of all 120 torsion measurements was 1.5° and the maximum deviation of 41 leg axis measurements was 0.5°. The maximum error of intra- and interobserver variability of the femur length was 3mm and 6mm, tibia length 6mm and 6mm, leg length 5mm and 5mm, femur torsion 5° and 7°, tibia torsion 5° and 7°, leg torsion 6° and 8° and leg axis 1° and 1.5°. The standard deviations of all measurements calculated according to the mixed model method are shown in fig. 1
After 50 measurements there was no statistically significant difference between the two investigators.

![Graph showing standard deviations of all measurements](image)

**Fig. 1:** Standard deviations of all measurements (n=100) calculated according to the mixed model method

**Discussion:** Up to now, the 2.5D ultrasound is not a standard procedure in the clinical routine. The main reason for this is the fact that a special navigation system (ZEBRIS®) is necessary. This system is not applicable in the operation room. With the Orthopilot® navigation system this problem no longer exists. Our measurements have shown that the accuracy increased significantly. The accuracy and reproducibility of this system is as good as CT scans and long standing x-rays. After 50 measurements the results are independent on
the investigator. Today the Orthopilot® system is the leading navigation system in orthopaedic surgery. To perform a 2.5D ultrasound measurement with this system, only the ultrasound tool and the software is necessary. Further possible applications are the intraoperative measurement of the leg geometry after intramedullary nailing or the intraoperative control of the real leg length after total hip implantation.

References


Surgical tool localization from 3D ultrasound volumes using 3D phase-based features

HACHALILOGLU I, ABUGHARBEH R, HODGSON AJ, ROHLING RN1,2, O’BRIEN P, GUY P

1 Department Of Electrical And Computer Engineering, University Of British Columbia, Vancouver, BC, Canada
2 Department Of Mechanical Engineering, University Of British Columbia, Vancouver, BC, Canada
3 Department Of Orthopaedic Surgery, University Of British Columbia, Vancouver, BC, Canada

ilkerh@ece.ubc.ca

Introduction: Three dimensional ultrasound (3D US) imaging is a promising candidate for replacing ionizing radiation-based modalities such as x-rays and computed tomography (CT) scans, which currently dominate imaging tasks in orthopaedic surgical procedures. However, to date it has not been possible to achieve accurate, robust and automatic localization of bone surfaces and surgical tools using 3D US due to the low signal to noise ratio in US data and the many artifacts present which significantly complicate image interpretation. In our previous work [1,2], we showed that two dimensional (2D) local image phase features, extracted using 2D Log-Gabor filters, gave promising results for bone surface and surgical tool extraction from US data. In this paper we report quantitative localization results of this 2D method for extracting surgical tools and also extend it to 3D using 3D Log-Gabor filters [3]. The capabilities of the 3D extension are validated through in vitro experiments.

Materials and Methods: To investigate the ability of our proposed 2D local phase method to localize surgical tools in US images, an experiment was conducted to assess the resolution of the tool localization relative to a simulated bone interface in both a water bath and in a more realistic tissue model; in both experiments, the surgical tool was a K-wire with a diameter of 1.6 mm. In the first part of the study, the bone was modeled using a flat metal block and
the tissue was modeled using a water bath. In the second part of the study, the bone was modeled using a plastic bone model (Sawbone model #1018-3, Sawbones Inc., Vashon WA) and the tissue was modeled using a 2 cm thick piece of bovine muscle tissue. The wire, shown in Fig. 1, was fixed to a stylus which was tracked with an optical tracking system (OPTOTRAK 3020, NDI, Canada) which is accurate to approximately 0.1 mm in each cardinal direction. The optical tracking system measured the tool tip position with an RMS error of 0.12mm, so it can be considered the gold standard. The stylus was rigidly mounted onto a clamp which could be repositioned relative to the bone model’s surface. The distance from the tool tip to the specular surface (Sawbone or metal block) was incrementally decreased by reducing the vertical distance while maintaining the horizontal position. After each position change we verified that the tool tip was in essentially the same position in the horizontal plane. The range of displacements in the vertical direction was 1.73mm to 6.39mm for the water medium and 2.01mm to 7.04mm for the bovine tissue medium.

In order to detect the tip of the K-wire, the US image was first processed using the local phase algorithm. Next, an edge detection algorithm was applied to the phase image in order to identify the inferior edge of the tool tip, which was defined as the pixel closest to the metal block’s surface. The distance from this pixel to the metal block surface was recorded as the displacement in the image domain. Changes in this distance were compared to changes in vertical position obtained from the optical tracking system.

To test the 3D extension of the algorithm, a rotationally symmetric 3D Log-Gabor filter was constructed with two components: a radial component, which responds to different spatial frequencies, and an angular component, which responds to different orientations [3]. The main difference between our 2D and 3D Log-Gabor filters is in the angular component since it extends the range of viewing angles of the filter beyond a single plane at a time. The 3D US data was processed by convolving the volume with a range of 3D filters constructed with a range of spatial bandwidths and orientation parameters.

In non-ultrasound-based applications of local phase filtering, the outputs of the various filter responses are normally combined to produce a single feature map [4]. However, we have observed that due to the directional characteristics of ultrasound, orientations perpendicular to the specular surface (K-wire or bone) tend to produce stronger responses to the surgical tool surfaces, while other orientations are more sensitive to ultrasound data artifacts. Therefore, instead of combining all filter responses, we relied on prior knowledge of the
ultrasound image formation to combine the filter responses that provided the strongest echoes from the surgical tool. Finally, we applied thresholding to the 3D volume to extract the strong bone feature responses from the remaining weaker features.

Results: The tip of the K-wire was localized with a mean maximum localization error of 0.4mm when the tool was imaged inside the water tank. This number increased to 0.8mm when the K-wire was imaged inside the soft tissue. Figure 1 shows that the 3D Log-Gabor filter successfully extracts 3D features corresponding to the surgical tool and the bone surface and it strongly attenuates US artifacts. There was remarkable separation of the K-wire from the bone surface and soft tissue, especially given the near-invisibility of the K-wire on the standard B-mode image.

Discussion: In our previous 2D studies, we showed that the bone surface could be accurately localized. Here we show that even relatively small surgical tools (less than 2 mm in diameter) can be localized with submillimetric resolution in a soft tissue model. In addition, we have shown qualitatively that a 3D generalization of the local phase filter can produce remarkably clear images of the surgical tool positioned above a simulated bone surface. Since the local phase algorithm can be performed essentially automatically, these results suggest that ultrasound can likely be used to track both surgical tools and bone surfaces in computer-assisted orthopaedic procedures such as fracture repairs. In the near future, we expect to test the algorithm with in vivo 3D US scans obtained from patients with fractures in order to evaluate the diagnostic utility of local phase images.
References


3d Navigation Guided Arthroscopy

TANG N, LEE KS, NG WK, LEUNG KS

Department Of Orthopaedics And Traumatology, Prince Of Wales Hospital, Shatin, Hong Kong

ntang@ort.cuhk.edu.hk

Introduction: Arthroscopic surgery has many advantages over traditional surgery and this minimally invasive technique is now widely practiced for different joint pathologies. Although the arthroscope allows the surgeon to observe the joint, extra skill is required to associate the camera image with the actual patient anatomy. Thus computer-aided navigation for arthroscopic hip surgery using encoder linkages for position tracking had been developed. A navigation system for shoulder arthroscopic surgery was also designed to improve the surgeon’s perception of the three-dimensional space within the human shoulder. Navigation for knee arthroscopy has also been reported as early as year 2000. However, these were the few literatures addressing the technical side of the navigation combine with arthroscopy limited to laboratory experiment. We report our early clinical experience of employing 3D navigation guided arthroscopy in 5 trauma patients. 3D image guided navigation could be used for indirect fracture reduction and fixation of fracture fragments and navigated arthroscopy could decrease the difficult in anatomy recognition, help verifying fracture reduction and identifying associated intra-articular derangements (e.g. meniscal, cruciate ligament or chondral injuries). This was especially useful in trauma where haemarthrosis and distorted anatomy are present.

Materials and Methods: Patients with minimally displaced and sizeable fragment posterior cruciate ligament (PCL) avulsion fractures or tibial plateau fractures were recruited. Pre-operative high resolution CT scans were acquired for fracture delineation and surgical planning. The CT data in DICOM format was then imported to 3D Spine program of Stryker-Leibinger Navigation System. Active infra-red tracker was then anchored to patients' tibia and intra-operative 3D fluoroscopy performed using the Siemens Sirmobile ISO-C 3D. For all the cases, only one passage for each of the guide wires was needed and then the screws of appropriate length were inserted. By performing fusion of
pre-operative high resolution CT and intra-operative 3D fluoroscopic images, registration was transferred to high resolution images. This enabled better fracture delineation and a larger working volume for 3D navigation procedures. 3D Image navigation guided insertion of guide wires follow by cannulated screws insertion was then performed. Intra-operative 3D fluoroscopy were performed again for verification of the screws’ optimal position and double checked for any cortical perforation. The tool tracker was then mounted to the arthroscope and calibration performed. Knee arthroscopy was then performed with the arthroscopy monitor placing side by side with the navigation monitor. The knee arthroscopy was then performed under direct arthroscopic image guidance and also real time display of the arthroscope position. Other instruments like probe or shaver had also be navigated similarly. The arthroscope was navigated to the exact fracture line for verification of fracture reduction and also to the exact position where the screw tip was placed subchondrally close to the articular surface. Associated intra-articular meniscal, ligamentous injuries or chondral damage were also explored and tackled accordingly. Post-operatively, all the patients were allowed immediate full weight bearing walking. One patient has concomitant tibial shaft fracture was treated by intramedullary nailing at the same operation. The patients were then followed up at 4, 8, 12, 24, 36 weeks post-op. Hughston’s criteria were used to assess the clinical results of the PCL alvusion fractures.

**Results:** 5 patients were reported in this series. There were three male and two female patients with age from 22 to 72 years old (average 51 years old). There were three PCL avulsion fractures and two tibial plateau fractures (Schazker type I and II respectively). The mechanism of injury include road traffic accident (2) and fell from height (2) and one fell on level ground (acoustic neuroma). The patients were followed up for average 34 weeks (from 26 to 40 weeks) The intra-operative navigation guided arthroscopy finding included

1. Haemarthrosis in all five cases
2. No other associated intra-articular pathology in the three PCL avulsion fractures
3. Schazker I tibial plateau fracture with associate medial femoral condyle chondral lesion (Grade II) and antero-lateral meniscal tear (arthroscopic assisted repair done)
4. Schazker II tibial plateau fracture with associate ACL and PCL tear

The fractures were noted to have healed by average 7.6 weeks (6 to 12 weeks). According to the Hughston’s criteria, the objective and subjective assessment for PCL avulsion fractures were good in all three patients while the functional score was good for two patients and one could not be assessed due to acoustic
neuroma undergoing treatment. The tibial plateau fracture patients both reported painless and full active range of motion in the injured knee. No intra-operative complications were recorded.

Discussion: We have proven the clinical applicability of combining two minimal invasive surgery technologies employed in orthopaedic surgery. All the patients recovered speedily from the injury and with very good functional result. From our experience we found that 3D image guided navigation arthroscopy helped the surgeon to identify anatomy within a joint when there was difficulty with arthroscopy alone due to altered anatomy or blocked arthroscopic view e.g by haemarthrosis. Also it helped fracture reduction by studying the articular stepping or by indirect measurement of navigated tools’s tip at the articular surface. We also foresee the application for tackling lesions hidden from the arthroscopic view from the articular surface e.g. subchondral cysts, avascular necrosis or in situation where arthroscopic assessment is inaccurate e.g. subacromial decompression by shoulder arthroscopy. However specially designed trackers and instruments will be needed so that there will not be blockage of the trackers by the arthroscopy instruments and vice versa.

References

Navigated Placement Of Scaphoid Screws With 3-d Fluoroscopy

CITAK M1, HUFNER T1, O’LOUGHLIN P2, OSZWALD M1, KRETTKE C1, GAULKE R1, STÜBIG T1, KENDOFF D2

1 Trauma Department, Hannover Medical School
2 Orthopaedic Department, Hospital For Special Surgery, New York

citak.musa@mh-hannover.de

Introduction: Image based navigation has been able to increase precision and reduce intraoperative radiation time in various drilling procedures in orthopaedic trauma indications. However due to specific anatomic conditions and necessary adequate fluoroscopic visualizing, specific indications do need intraoperative 3-D fluoroscopy based navigation modalities. 3-D based fluoroscopic based navigation has already been successfully implemented in sacroiliac-screw placements, spinal pedicle screw placement, drilling of osteochondral and tumor lesions at al extremities. The complex anatomic structure of the scaphoid, the suggested minimal invasive operative procedure and misplacements rates of the osteosynthetic screws, does not offer appropriate 2-D based fluoroscopic navigation for a precise osteosynthetic screw placement. Missing options for a stable reference marker fixation at the scaphoid or carpus did not allow an intraoperative registration process for the navigation system so far. We therefore report about the development of a adequate non invasive fixation technique of the reference marker for navigated interventions at the carpus including the first implementation of 3-D fluoroscopy based navigated placement scaphoid screws.

Materials and Methods: Fixation of the reference marker was achieved by immobilisation of the complete hand and forearm in maximum dorsal extension of the wrist. Therefore the extremity was fixed to a complete newly developed radiolucent hand fixation device (HFD). Consequently no rest mobility of the carpus and all related joints in the hand were possible. After immobilisation, fixation of the reference marker was done at the HFD, non invasive to the carpus.

A conventional navigation system (Brainlab, Germany) in combination with 3-D fluoroscopic imaging (Iso-C, Siemens, Germany) was used, and a full scan
of the carpal region performed. Tests were done on 10 intact specimen (forearm including hand). The navigated procedure included the initial drilling procedure and final placement of a retrograde inserted osteosynthetic screw into the scaphoid. No further imaging was done during the procedure. Postoperative placement control was done with a secondary 3-D scan directly afterwards. Results concerning a defined optimal screw positioning, misplacements, drill failures and drill attempts were blinded done by another surgeon.

**Results:** All 3-D scans were done without complications. The multiplanar reconstructions did allow a proper visualisation of the scaphoid in three planes in all cases. No additional movement of the fixed extremity occurred during the operative procedure. No registration failures do to reference marker motions or loosening were detected. An optimal defined achievable screw placement in the scaphoid was done in 9 cases. Two repeated drill attempts were necessary in one case, another case needed three drill attempts. No direct drill failures including perforation of the scaphoid were found.

**Discussion:** Our development of a new immobilizing device for the complete hand and forearm does allow proper use of 3-D fluoroscopy based navigation at the scaphoid. Proper immobilisation of the carpus does allow a secure placement of an osteosynthetic screw, without invasive fixation of the reference marker.
However further movements of the hand or fingers are intraoperatively only possible after the definite drill placement has been performed. The 3-D imaging modality does also allow a direct control of the reduction and screw placement intraoperatively. Our tests did not include simulated fracture conditions, therefore a general use of our new technique can now only be implemented to non displaced fracture types, while clinical and further laboratory tests have to improve our findings for all types of scaphoid fractures.
Navigated Control In Reduction Of Tibial Plateau Depression Fractures

HÜFNER T¹, KENDOFF D², BRETTIN P¹, O’LOUGHLIN P², STÜBIG T¹, KRETTEK C¹, OSZWALD M¹, CITAK M⁰

¹ Trauma Department, Hannover Medical School
² Orthopaedic Department, Hospital For Special Surgery, New York

citak.musa@mh-hannover.de

Introduction: Precise reduction of the articular surface in tibial depression fractures is critical to allow successful weight bearing and prevent early arthritis of the knee joint. Consequently, prevention of post-traumatic arthrosis which is associated with pain and loss of function should be achieved. The objective of our study was to evaluate whether a novel, minimally invasive navigated technique could successfully reduce tibial compression fractures using a Kyphon balloon.

Materials and Methods: The first step involved developing a cannula which could be calibrated with the navigation system (VectorVision, Brainlab, Feldkirchen, Germany). A Kyphon balloon (Kyphon, Brüssel) could be inserted into the cannula. The cannula’s design permits the Kyphon balloon to develop its inflational force only in the cranial direction. We used the Iso C 3D (Siemens, Erlangen, Germany) navigated module, which allowed for a precise placement of the cannula directly below the depression fracture (AO 41-B2, Schatzker type III). In our pilot study we used a cube (92mm x 55mm) which consisted of a synthetic bone material (Synbone, Switzerland). We simulated different depression-type fractures of varying diameters (2.5mm, 5mm, 14mm). The depth of the depression varied from 2mm to 4mm according to the different diameters of the mechanical impression devices used. Experiments were repeated 10 times for each type of depression. Each synbone was scanned by Iso C 3D after the depression injury was performed and the x-ray data was loaded into the navigation system. With the aid of multi-planar reconstruction we could calibrate the drill and navigate it to an area directly beneath the depressed area. Having calibrated the cannula we positioned the Kyphon balloon and inflated it to raise the depressed portion of Synbone. The balloon was deflated, removed and another Iso C 3D scan was performed.
In the second stage of the study we created depression fractures on the lateral portion of the tibial plateaus of 5 cadaveric tibiae. We used the impression device of 14mm diameter. The impression had to have at least this diameter to have clinical relevance. This was based on a prior study of the CT Scans of several patients with tibial depression fracture treated in our hospital. The tibiae with the depression injuries were scanned by Iso-C 3D. Following navigated drilling using a minimally-invasive technique, we placed the cannula directly below the depressed area of the tibial plateau. Reduction was achieved via Kyphon balloon inflation under permanent navigated control.

**Results:** The depression fractures in the Synbone cubes were seen to be reduced accurately. The depression fracture of 5mm diameter showed a remaining depression depth of an average of 0.26 mm and those of 14 mm diameter depth could be reduced to a depression of average 0.21 mm. However, the depression fractures of the cadaveric tibiae could not be reduced with our experimental setup. The force of the balloon compressed the cancellous bone below the cannula instead of lifting up the depressed portion of the plateau. The distance from the balloon to the impression grew because the force of the balloon moved the cannula in a caudal direction.

**Discussion:** While sawbones allow for a precise reduction of depression fractures with our novel balloon based technique, in cadaveric trials the force of the balloon displaced the navigated cannula in a caudal direction, without proper reduction of the fracture impression. An anchored cannula involving the medial as well as the lateral cortical bone, thus crossing the proximal tibia, may be able to reduce depression of the tibial plateau. We plan to test this hypothesis initially in cadaveric specimens in order to eventually establish whether our novel technique, involving the Kyphon balloon, can successfully reduce tibial plateau depression fractures in a clinical setting.
Patient Specific FEA Of Femoral Fracture Fixations: Methodology And Experimental Validation

Peleg E¹, Liebergall M², Juskowicz L³, Gefen A⁴, Mosheiff R²

¹ Department Of Medical Engineering, Hadassah University Hospital, Israel
² Department Of Orthopedic Surgery, Hadassah Hebrew University Medical Center, Israel
³ School Of Engineering And Computer Science, The Hebrew University Of Jerusalem, Israel
⁴ Department Of Biomechanical Eng, Tel Aviv University, Israel

eran@hadassah.org.il

Introduction: Choosing and executing an optimal treatment plan for skeletal fractures in clinical practice is a complex procedure. It requires integrating patient, surgeon, hospital, and fracture-specific factors such as patient condition; surgeon’s experience and preferences; availability of fixation devices and support staff; and fracture comminuting and bone/soft tissue quality. Fracture treatment decisions are particularly critical for medically debilitated patients; patients with poor bone quality; and multiple trauma patients. Treatment decisions are often qualitative, based on general guidelines, and can vary widely among orthopedists (Fig 1a).

Computer-Aided Orthopaedic Surgery (CAOS) techniques have the potential to provide the support to improve fracture treatment. However, the key quantitative patient- and fixation-specific biomechanical information is currently unavailable. Specifically, no quantitative biomechanical analysis of load bearing bone fixation is currently available in the clinic. While there is ample literature on patient specific biomechanical Finite-Element Analysis (FEA) [1-3], it focuses on stress/strain distribution and fracture risk assessment of intact bones. Existing software requires a significant and time-consuming technical effort to generate the bone model for FEA and to interpret its results, thus precluding its clinical use in the foreseeable future.

We are developing novel patient-specific computer-aided quantitative planning and analysis methods to assist surgeons in fracture treatment planning. The
planning will assist surgeons in optimal fixation hardware type, size and position selection based on objective and measurable biomechanical considerations. This study presents the modeling and validation methodology and our preliminary results.

**Materials and Methods:** The modeling and validation methodology is shown in Fig 1b. It consists of computer model generation (M1-M5) from a CT scan, FEA, comparative analysis, physical testing on the actual fixated bone (P1-P3), and validation. Model generation (Fig 1c) consists of geometry extraction, fracture reduction, implant positioning, automatic volumetric meshing; and material property assignment based on an empirical Young modulus relationship where \(a,b\) are empirical constants and is bone mass density [2]. FEA uses linear model with quadratic 10-node tetrahedral elements [3]. Comparative analysis compares the strain patterns between the fixated femur and the same intact femur (Fig 1e). Physical testing operations include fracture fixation, axial loading test of the fixated femur (Fig 1d); and a three point bending test of the femur shaft for calibration purposes. Validation consists of comparing the simulation rand the physical testing results.

For validation, an intact femur was harvested from a fresh perfused cadaver [4]. A 31-A1 extra-articular fracture (pertrochanteric simple) was introduced, followed by a CT scan. Model generation, FEA, physical testing, and validation was then performed as described above. Sensitivity analysis with Principal Component Analysis (PCA) and Strain Value Ratio (SVR) analysis was also performed to assess the sensitivity of the proposed methodology to changes in the Young modulus relationship and inaccuracies in boundary constraint positioning.

**Results:** Excellent correlation was found (Fig 1e) between the physical axial loading test and the FE analysis in the linear region prior to thread loosening. The slope of the force versus deflection was 349.8 [N/mm] \(R^2=0.9912\) for the physical test and 371.6 [N/mm] \(R^2=0.9911\) for the FE simulation. The comparative methodology showed low sensitivity to changes in the Young modulus relationship. For eight different models using a different Young modulus relationship (550<2000, 2.7<3.1) the SVR was 80.475+-3.38\%, the mean angle of all principal eigen vectors was, 2.26+-0.83\% and the mean STD of ratios between all eigen values was 10.17\%. For small changes in boundary constraint location (arbitrary 5 mm relocation of load positioning on the femur head), our comparative methodology showed higher sensitivity in the femur head than in the femur shaft; for the femur head the mean angle of all principal eigen vectors was 4.87+-3.51\(\circ\) and the mean STD of ratios between all eigen
values was 39.95%. For the femur shaft, the mean angle of all principal eigen vectors was 0.81±0.0° and the mean STD of ratios between all eigen values was 2.4%. The SVR value was insensitive to small changes in boundary constraint positioning; SVR was 78.01±2.09%.

Discussion: A complete methodology for computer assisted fracture treatment, including biomechanical analysis, is presented. The methodology has been tested and validated for a simple fixated intertrochanteric fracture in the proximal femur. The technique of comparative computation, presented in this study has the benefit of intuitive presentation of strain patterns that develop in the fixated bone relative to the same specific intact bone and was found to be insensitive to changes in the Young modulus relationship. Patient specific FEA was implemented in a fractured femur resembling a future clinical workflow. The methodology presented has the potential to assist the clinician in executing an optimal treatment plan for skeletal fractures in clinical practice.
Arthroscopy and Fracture Reduction

References


A Fluoroscopically Based Navigation System For ACL Replacement Surgery: Development, Precision Analysis And Comparison Of 2d Planed Positions With Their Navigated 3d Counterparts

HOFBAUER VR1, KOENIG B2, RUEBBERT A1, HAAS NP3, RASCHKE MJ1, STÖCKLE U2

1 Trauma-, Hand- And Reconstructive Surgery, University Clinic Muenster, Westfalian Wilhelms University, Muenster, Germany
2 Dept. Of Traumasurgery And Orthopedic Surgery, University Clinic Right Of The Isar, Technical University Munich, Munich, Germany
3 Trauma- And Reconstructive Surgery, Charité University Clinic Berlin, Berlin, Germany

vincent.hofbauer@web.de

Introduction: In anterior cruciate ligament (ACL) reconstruction surgery correct femoral tunnel placement is of paramount importance for a good clinical outcome (Musahl et al. 2004, Petersen et al. 2006). In spite of a better understanding of the anatomy and new methods of surgery outcome is still poor with revision rates up to 10%. The aim of this study was to develop and validate a fluoroscopically based navigation system for precise tunnel placement. We followed the hypothesis that an integration of conventional geometrical templates into the navigation system allows a precise and reproducible tunnel placement.

Materials and Methods: For determination of the systems precision the positions for tunnel placement were planed using three different 2D templates, found at the 3D anatomy of artificial femurs with the help of the navigation system and marked with a 0.5 mm lead balls (n=40). The resulting 120 coordinates were statistically compared with the planned positions. In a second part the influence of projection errors as a result of rotations of the femur models along the longitudinal and transversal axis was investigated. Starting with a true
lateral x-ray of the femur, rotations in 1° steps were done for all directions. Each step of rotation followed an x-ray and the coordinates of the lead ball was compared to the aimed ones. For visualization of errors in 2D planning with the templates 10 2D concentric circles and 8 lines were drawn around the planned ACL insertion sites. These lines were projected on the 3D anatomy of the femur models using the navigation system. The geometrical shapes were statistically compared. After experimental validation of the system it was tested in 5 navigated ACL reconstructions in our clinic.

Results: Insertion sites could be determined with a high precision. Mean deviation from the target value in proximal-distal (PD) and anterior-posterior (AP) direction was less than 1.00 mm for all three used templates. In PD direction the template by Hertel et al. (1996) showed a significant lower deviation from the target value compared with the template by Klos et al. (2000). Deviations in AP direction were significantly lower compared with the two other templates. The error in PD direction resulting from rotation of the femur model was 0.31% (0.07 mm) per 1° rotation along the longitudinal axis and 0.36 % (0.17 mm) for AP direction. For rotations along the transversal axis it was for PD 0.25 % (0.06 mm) and AP 0.64 % (0.30 mm) per 1° rotation. In clinical use the system was more efficient and user friendly than commercial navigation systems even though the direct line of sight (IR-camera / referenced navigation instruments) is often blocked by the instruments used during the surgery.


**Discussion:** The described navigation method allowed a precise placement of the drill holes for ACL replacement. Compared to conventional systems it is easier to maintain and more time efficient. Through integration of the 2D templates, ACL insertion sites could be transferred to the 3D anatomy of the knee. Precise position of the tunnels can only be achieved with true lateral x-rays of the knee. Further studies have to be done to test the systems clinical performance and impact on long term results after ACL reconstruction.
Measuring The Position Of The ACL Footprint With A Navigation System - Comparison With X-Ray, CT-Scan And Anatomic Measurements

JENNY JY, CIOBANU E, BOERI C

Orthopaedic Department, University Hospital, Strasbourg, France

jean-yves.jenny@chru-strasbourg.fr

Introduction: Anterior cruciate ligament (ACL) reconstruction allows overall good results, but there is still a relevant rate of failure. It is well accepted that the main reason for ACL reconstruction failure is a misplacement of tibial or femoral tunnels. Conventional techniques rely mainly on surgical skill for intra-operative tunnel placement. It has been demonstrated that, even by experienced surgeons, there was a significant variation in the accuracy of tunnel placement with conventional techniques. Navigation systems might enhance the accuracy of ACL replacement.

Materials and Methods: 10 cadaver knees with intact soft-tissue and without any intra-articular abnormalities were studied. We used a non image based navigation system (OrthoPilot®, Aesculap, Tuttingen, FRG). Localizers were fixed on bicortical screws on the distal femur and on the proximal tibia. Both cinematic and anatomic registration of the knee joint were performed by moving the knee joint in flexion-extension and palpating relevant intra-and extra-articular landmarks with a navigated stylus. The most anterior, posterior, medial and lateral point of both tibial and femoral attachment of the ACL were marked with metallic pins. The navigated stylus was positioned on these points, and the system recorded its position in comparison to the bone contours. Subsequently, we performed conventional plain AP and lateral X-rays and a CT-scan, and measured the position of the pins in comparison to the bone contours. Finally, all measurements were made again with a caliper after disarticulating the knee joint. We calculated the center of the footprint as the mid-point between the four pins of both tibial and femoral attachment for each measurement technique. All measurements were expressed as percentages of
the bone size to compensate for the different sizes. The results were analyzed with a Friedman test with post-hoc comparison, considering the anatomical measurements as the reference.

**Results:** The mean medio-lateral position of the tibial tunnel was (origin at the lateral tibial border): 52% (SD 2%) for anatomical measurement; 50% (SD 2%) for navigated measurement; 49% (SD 2%) for CT measurement; 51% (SD 2%) for X-ray measurement. The differences were globally significant (p<0.001); there was a significant difference between the reference and navigated and CT measurement techniques.

The mean anterio-posterior position of the tibial tunnel was (origin at the anterior tibial border): 53% (SD 7%) for anatomical measurement; 50% (SD 7%) for navigated measurement; 50% (SD 7%) for CT measurement; 50% (SD 7%) for X-ray measurement. The differences were globally significant (p=0.03); there was a significant difference between the reference and the radiological measurement technique.

The mean proximo-distal position of the femoral tunnel was (origin at the distal femoral border): 75% (SD 12%) for anatomical measurement; 78% (SD 15%) for navigated measurement; 80% (SD 11%) for CT measurement; 74% (SD 12%) for X-ray measurement. The differences were globally significant (p=0.05); there was no significant difference between the reference and any measurement technique.

The mean antero-posterior position of the femoral tunnel was (origin at the anterior femoral border): 79% (SD 13%) for anatomical measurement; 83% (SD 19%) for navigated measurement; 85% (SD 14%) for CT measurement; 77% (SD 15%) for X-ray measurement. The differences were globally significant (p<0.01); there was no significant difference between the reference and any measurement technique.

**Discussion:** Anatomical measurement of the location of the ACL footprint is the gold standard in an experimental situation. CT-scan measurement of the positioning of the ACL replacement tunnels is the gold standard in a clinical situation. X-ray measurement of the positioning of the ACL replacement tunnels is the most used technique in a clinical situation. Navigation might help improving the accuracy and the reproducibility of ACL replacement. However, the precision of each system has to be evaluated. The measurements by the OrthoPilot system were significantly different from the anatomical reference, but the difference appeared to be clinically not relevant. We concluded that this system allowed locating in a precise and accurate way the position of the ACL footprint on both tibial and femoral sides when compared to the reference
techniques. This navigation system is precise and accurate for anatomical measurements in the knee joint. This should help the surgeon to define the placement of the tunnels according to anatomical landmarks during ACL replacement. The OrthoPilot navigation system is precise and accurate for anatomical measurement of the tunnel placement during ACL replacement.
Navigation Accuracy Analysis Of ACL Reconstruction With Two Tracking Modes

SUN L1, HU Y2, WANG JC2, FENG H1, LIU WY2, WANG YW2, WANG MY1, WANG TM2

1 Beijing Institute Of Traumatology And Orthop, Jishuitan Hospital, Beijing, China
2 Robotics Institute, Beihang University, Beijing, China

dr_sunlei@sina.com

Introduction: Remarkable results have been achieved in the technical innovation and application of the medical robots[1]. Robot-assisted navigation could provide effective means to solve this question because it can improve the operation positioning accuracy, and it is more steady and credible than the human. Last year, a novel navigation system for ACL reconstruction based on the passive tracking mode with the visual light vision sensor MicronTracker2.7 (MT) and the experiment on a plastic femoral bone have been described. In the past year, 5-DOF passive robot which applied to exact manipulation for ACL reconstruction has been designed and developed in order to promote the navigation system to closely follow the pace of development in the world. It has been proved by experimented results that be traced in the infrared photoelectric sensor NDI is more than the video sensor MT. Based on real-time monitoring with MT, infrared photoelectric sensor NDI is also used in the system. In tracing with NDI, collecting of femur/tibia surface characteristic, reconstruction of bone surface and positioning of navigation robot can be performed. With this system, we have implemented operation planning based on front/lateral fluoroscopic image, anisometry evaluation of the reconstructed virtual ACL in tracing of NDI, and movement of the skin relative to the bone through 10 plastic bones (Synbone, Swiss) and 5 animal bones experiments. In addition, we have performed collecting of unorganized points on the bone surface in tracing of MT and NDI respectively, and compared two results.

Materials and Methods: System structure: The system is initially designed to assist the surgeon to carry out the surgical planning, the entry positioning of
implant tunnels, the anisometry measurement, the joint kinematics evaluation, and eventually to validate performances during the apparatus tracking. Besides functional modulus of hardware (such as MT, the video frame grabber) and software (image acquisition, the image dewarping, the quadrant-based femoral entry planning, display of tunnel on the fluoroscopic, collection and reconstruction of the bone surface, anisometry measurement), the photoelectric sensor NDI and the 5-DOF robot have been introduced into this system to improve the navigation accuracy.

Material: 30 3D targets (the steel ball with 3 mm diameters) on a plastic femoral bone (Synbone, Swiss) are adopted to test the final positioning accuracy of the entire system. 5 fresh front legs of pig are used for the experiments described above. The optical position measuring sensor MicronTracker2.7 (Clarontech, Toronto, Canada) is used for monitoring the information of environment in real time. The photoelectric sensor NDI (Northern Digital Inc, Waterloo, Canada) Spectra is used for extraction of the bone surface, the joint kinematics simulation, anisometry evaluation and robot navigation.

Experimental Procedure: Experiment platform is showed in Fig.1. The basic operation steps are described as following: (1) Installing the home made marker which can be tracked by MT and NDI synchronously on the femur and tibia of the leg, and pasting a marker traced by MT on the skin; (2) Fixing the femur, and measuring the movement of the skin relative to the bone when the tibia is moving; (3) Extraction from bone characteristic, surface reconstruction, ACL virtual reconstruction, anisometry measurement and kinematics evaluation in tracing of MT and NDI respectively, and comparing two results; (4) Performing the experiment following the method described by Sun[2] to measuring the position accuracy of the whole navigation system.
Results: In the course of rotating the tibia, the experimental data showed that the minimum value of the skin relative to the bone is 6mm and the maximum is 12mm in tracing with MT. The result testified that the method of pasting marker just on the skin instead of the bone can not fully meet the requirement of the operation. Moreover, reconstructed bone surface in tracing of MT is more excellent than in tracing of NDI by comparison the results got with two tracking modes respectively, which can prove that NDI can improve the accuracy and security of operation. The accuracy tests give out a resulting positioning error less than 1.8 mm.

Discussion: MT can provide intuitionistic vision effect because it can monitor the real-time video and information in the operation environment. However, its tracking accuracy cannot be satisfied with the ACL reconstruction operation and it’s lack of enough stability to the light variation has also been testified by experiments repetitively. The infrared photoelectric sensor NDI can not make the environment be visible, but it can make up the disadvantage of MT appropriately because not only it can improve the tracking accuracy, but also it has enough stability. There is the result of the MT’s accuracy as well as the distortion of marker for the evident displacement of the skin relative to the bone in tracing of MT. So it needs to perform experiment using NDI. 15 experiments have been implemented with this system successfully, which prove the feasibility of operation planning on front and lateral X-ray and the accuracy of the entry positioning of implant tunnels in tracing of photoelectric sensor. The location accuracy has reached the leading clinical standard of the world’s navigation system. However, we have to try to performing experiment on a lot of animal’s bone and cadaver with this system, testing and improving the accuracy of assisted robot for navigation, and drilling tunnels on femur and tibia navigated by the robot.

References
In-vivo Investigation Of Lumbar Spinal Instability Using An Instrumented Spinal Distractor

AMBROSETTI S¹, PFENNIGER A¹, KRENN M², PIOTROWSKI W³, BÖCHLER P¹, KOWAL P¹, NOLTE LP¹, BURGER J¹

¹ University Of Applied Sciences Bern, Laboratory Of Biomedical Engineering, Biel, Switzerland
² Christian-Doppler-Clinic, Department For Neurosurgery Pmu, Salzburg, Austria
³ MEM Research Center, ISTB, University of Bern, Switzerland

sveva.ambrosetti@bfh.ch

Introduction: Diagnosis of spinal instability is still controversial. The importance of the various parameters collected preoperatively for the diagnosis is unclear. Because of the lack of an effective diagnosis procedure, sensing the spinal stiffness during surgery has become a common procedure. Spinal stiffness is indeed recognized as the most significant parameter for the assessment of spinal instability [1]. A distractor for conventional dorsal spinal fusion surgery was instrumented with sensors for real-time measurements in order to quantify spinal stiffness during decompression surgery. The objective of this study is to evaluate how the measured stiffness correlates with spinal instability.

Materials and Methods: In an on-going in-vivo clinical study, intra-operative spinal stiffness measurements before and after decompression surgery are performed in the lumbar spine while muscles are completely relaxed [2]. In order to guarantee the same level of muscle relaxation for every measurement a neuromuscular monitoring system was attached to the patient. The elimination of the muscles parameter allows a better comparison of measurements between men and women. This study is based on two groups of patients, one showing clinical signs of spinal instability (5 patients), and one not (21 patients). Since January 2006, spinal stiffness has been measured on 26 patients (14 men and 12 women).
Results: The stiffness difference between the two groups is not significant. However, data comparison obtained from all the patients between pre and post-decompression measurements shows a clear tendency of the spinal stiffness to decrease after surgery. It is known that the partial removal of an inter-vertebral disc creates a temporary instability of the spinal segment; hence, this preliminary result demonstrates a correspondence between intra-operative measurements of spinal stiffness and spinal instability.

A deeper investigation on the group of patients without signs of spinal instability (and medium level of disc degeneration) shows that performing standard microdiscectomy generates a decrease in stiffness (average decrease of the 21 patients is 24%) [3]. From a biomechanical point of view our results would support a fragmentectomy-only-approach in case of disc prolapse and MRI 3° degeneration to reduce iatrogenic loosening of the spinal motion segment.

Discussion: Data collected until now were measured with the help of the first distractor prototype. The development of the second generation of the instrument is currently at the final stage. The new instrument was designed following the needs of the surgeons and hospitals (steam sterilization instead of gas). Integrated force sensors, improved characteristic of the distance sensor and a fully automatic calibration system (used before every measurement) allow to reach a high level of accuracy and repeatability in the measurements. A wireless communication system has been developed, which facilitates the surgeon’s movements. Moreover, the implemented thinner tips imply a less invasive approach. The use of the second prototype will allow a deeper investigation of the correlation between measured stiffness and spinal instability.
References


Application And Valence Of The 3d-C-arm In The Cervical And Upper Thoracic Spine

Jarvers JS, Katscher S, Franck A, Riesner HJ, Blattert T, Siekmann H, Josten C

Department Of Traumatology And Spine Surgery, University, Leipzig, Germany

jan-sven.jarvers@medizin.uni-leipzig.de

Introduction: In the last years, navigated surgical procedures in spinal surgery have been established because of an increasing demand for precision. Especially 3D-C-arms connected with navigation systems are used more often and can be utilised intraoperatively for planning as well as controlling of posterior instrumentation, concerning even technically demanding areas like the cervical and thoracic spine. Also anterior procedures, such as resection of posterior wall fragments in unstable fractures with neurologic impairment, can be performed under navigation-assistance. The aim of this prospective study is to show the use of the 3D-navigation in clinical use, also compared to the CT-based navigation.

Materials and Methods: A 3D-C-Arm (Vision Vario 3D, Fa. Ziehm) was connected with a navigation system (Vector vision, Fa. Brainlab) and tested on 13 patients (3x cervical spine, 10x thoracic spine) for lateral mass screws and transpedicular screw placement. Indications for the instrumentation were 5 traumatic fractures, 5 osteolytic metastases, 2 spondylodiscites, and 1 degenerative rheumatic stenosis of the spinal canal.

Results: The intraoperative scan-time took almost exactly 1 minute, the data-transfer to the navigation computer less than 10 seconds. The application-time including anti-collision-check lasted 5 to 18 minutes. 85% of 96 screws were navigated. In the one case of degenerative rheumatic stenosis of the spinal canal the planning-scan in the upper thoracic spine could not be used because of artefacts caused by a bilateral shoulder-prosthesis. Concerning scan-quality and the ability to navigate, adipositas and osteopenia were limiting factors.
Technical problems could be found during scan- setup, especially regarding the identification of the C-arm with the camera of the navigation- system as well as the collision- free scan in general. 74 % of the screws were controlled intraoperatively. Prior in the cases of the 5 patients with long distance stabilisations of osteolytic metastases we did not control every single screw to avoid a further prolongation of the intervention, as these tumor patients where in a critical health status.

The postoperative CT’s showed correct placements of the implantates in every case and correlated with the intraoperative controls.

**Discussion:** The application of the combination of both systems (navigation system and 3D C- arm) at surgeries of the cervical and upper thoracic spine is possible and works most of the time reliable in clinical use. Occurred sources of error depending user on the one and software on the other hand could be solved during the first course of the series. Regarding the operation time there certainly is a prolongation, at the beginning of the study mostly caused through the initial learning curve. In case of an error free use of the C- Arm a scan can be accomplished within 5 minutes. Concerning the application there are the same region based problems, especially in the cervicothoracal area, as in the CT-based navigation. In case of good radiological quality of the scan the reliability of the 3D- based navigation is at least coequal to the CT-based procedure and implies on the one hand a reduction of the exposure dose through the possibility of the abolition of the pre- and postoperative CT and therefore on the other hand a limitation of costs.
In Vivo Measurements Of The Bending Stiffness Of The Scoliotic Spine

REUTLINGER C1, KOWAL J1, BURGER J2, HASLER C3, BÜCHLER P1

1 MEM Research Center, ISTB, University of Bern, Switzerland
2 University Of Applied Sciences Biel, Switzerland
3 Universitätskinderspital Beider Basel, Switzerland

christoph.reutlinger@memcenter.unibe.ch

Introduction: Adolescent Idiopathic Scoliosis (AIS) is an orthopaedic disorder which is characterized by a lateral deflection of the spine and a rotation of the vertebrae. Although the cause of AIS is unknown, it is generally recognized, that the progression of the curve is due to biomechanical factors. Surgical correction is the only treatment that allows lasting reduction of the deformation. However, it does so at the expense of spinal motion, as the operation entails a bony fusion of a large portion of the spine.

In order to understand the principles of the curve progression, as well as to develop new treatment strategies and planning, a Finite Element model of the spine can provide essential information. However, material data and stiffness properties of motion segments are commonly only available for healthy, adult spines.

In order to obtain data for an appropriate Finite Element Model, in-vivo measurements of the bending stiffness are performed on adolescent patients. Scoliotic spines are instrumented after the opening of the back and before the actual corrective surgery.

Materials and Methods: A standard distraction forceps used for spinal surgeries was instrumented with two additional components. First, sensors were integrated to measure force and displacement. Secondly, active optoelectronic markers are attached to the forceps. During the surgery, five vertebrae around the apex of curvature are also equipped with optoelectronic markers. This setup enables the calculation of the 3D motion and consequently the orientation of the force vector with respect to the vertebrae. The forceps are applied between the transverse processes of two adjacent vertebrae and thus induce a rotational motion, which corresponds to a lateral bending (see Figure ).
As the sensors measure force and translational displacement, it is very important to know the point and the direction of action of the applied force. Thus, moments and rotational displacements and finally the bending stiffness can be determined. Moreover, the measurements are performed manually, which means that the forces are not applied in a constant and standardized way. With the chosen method, only the component of the force vector perpendicular to the axis of rotation can be considered when calculating the moment. This makes the results comparable to published data, as usually pure moments are applied when cadaveric spines are examined.

An additional challenge of this procedure is that it is based on MRI images. This limitation is due to the fact that the patients are young adolescents. The segmentation of the scoliotic spines is currently done manually. The accuracy of this approach was evaluated in several tests. For instance, two lumbar vertebrae of a cadaveric spine of a sheep were segmented from a CT and a MRI - scan. From a patient (no cadaver) two slightly different regions were recorded in a MRI scanner. Then, the same thoracic vertebrae were segmented. Both cases showed an error of approximately one millimeter.

Results: Three operations on right thoracic curves have been successfully performed so far. The results from these measurements show an increasing stiffness on the concave and a decreasing stiffness on the convex side towards the apex of the curve. Furthermore, a distinct nonlinear load displacement behaviour can be observed. The mean values correspond to the data published in the literature for the thoracic part of the spine.
**Discussion:** The objective of this study is to determine the variation of the stiffness along the scoliotic spine. One important benefit of the chosen approach is the integration of the navigation system in that it provides the 3D motion of both the vertebrae and the forceps. Thus, the determination of applied moments and the resulting angular displacement is possible. Additional measurements are required to provide statistically relevant data. The comprehensive description of the forces and motions measured during the studies will enable a good validation of scoliotic Finite Element models and provide a better understanding of the relation between the flexibility of the spine observed in bending films and the localized stiffness of motion segments. A long term perspective of these measurements is to enable the surgeons to have an accurate evaluation of the spine stiffness and thus to better plan their

Acknowledgement: We like to acknowledge the support of Synthes GmbH and BrainLAB AG for this work.

**References**
- Stokes et al, SPINE, 10:1162-1167, 1996
Accuracy In Navigated Total Hip Replacement With And Without Invasive Femur Locator

Hoffart R¹, Moser W²

¹ Kreiskliniken Darmstadt-dieburg, Seeheim-Jugenheim, Germany
² Smith & Nephew Orthopaedics AG, Aarau, Switzerland

w.moser@plusorthopedics.com

Introduction: Malpositioning of the cup in THR is still a major source of early complication in Total Hip Replacement. Navigated surgery has proven to improve the quality of cup angulation in THR 1, 2). Through navigated implantation of hip endoprostheses, cup orientation can be improved and leg lengths and offset differences of the joint can accurately be measured. For this, reference locators must be fixed at pelvis and femur in an invasive procedure. A disadvantage of navigated joint replacement procedures is the requirement for additional incisions to attach permanent bone reference marker fields. This applies particularly to regions with significant soft tissue overlapping, e.g. in the area of the femur. To be able to proceed without a femoral incision in particular during minimal invasive surgery, a method has been evaluated in terms of accuracy of the measurements, in which leg length and joint offset can only be determined using the pelvic locator.

Materials and Methods: In 20 navigated hip joint operations, in addition to the measurement of leg length and offset changes using respectively one pelvic and femoral locator (method A), a second measurement was performed using only one pelvic locator and, on the femoral side, a 2-point scanning method (method B). In method B, the leg was arranged in a neutral position on the operating table; before resection of the femoral neck, one point was marked and scanned close to the femoral neck resection level and a second point was marked and scanned close to the knee. During this, the point close to the resection level must be scanned exactly, whereas the point close to the knee joint is scanned with approximate accuracy. Following implantation, both points were recorded once again and the leg lengths and offset difference of the two methods was calculated based thereon. To ensure that the individual point
scanning is accurate, respectively one femoral and one pelvic confidence point were defined and checked.

**Results:** The average difference in leg length measurement between A and B is 1.0 mm (standard deviation = 1.2 mm); no tendency to longer or shorter leg length was detectable. The average difference in offset measurements between A and B is 1.4 mm (standard deviation = 1.7 mm). Slightly greater variations were determined compared to the leg length difference. Through multiple measurements on the same patient, with specifically abducted and specifically rotated leg, it was determined that the method is sensitive to changes in the neutral leg position as far as the offset measurement is concerned.

**Discussion:** The leg length measurement accuracy was insignificantly reduced when no femoral bone reference locator (B) was used. The slightly increased uncertainty during offset measurement appears to be acceptable as it is determined by the prosthesis models and can thus be influenced only slightly by the surgeon. Offset of the stem implant, morphology of the proximal femur and the available spectrum of hip spheres are the determining factors in this regard. Due to the high precision requirements with regard to repeated scanning accuracy of the femoral point close to the resection level, the method requires increased concentration compared to the standard method. In particular, the point close to the neck resection must clearly be marked to ensure reproducible retrievability. Alternatively, it can be marked using drill and electroscaletel, or a small bone screw can be fixed. Repeated scanning and statistical treatment has proven successful in reducing the influence of scanning accuracy and thus increases the safety of the method.

**References**


Acetabular Cup Orientation Using A Statistical Data Based Calibration Table

Dong X1, Echeverri S2, Nolte LP1, Vallotton P3, Zheng G3

1 MEM Research Center; ISTB, University of Bern, Switzerland
2 Santech Surgical Sarl And Clinique Bois Cerf, Hirslanden, Lausanne, Switzerland
3 Clinique Bois Cerf, Hirslanden, Lausanne, Switzerland

Guoyan.Zheng@MEMcenter.unibe.ch

Introduction: Acetabular component orientation is a significant factor that affects the risk of dislocation, impingement, acetabular migration, and wear between components in patients undergoing total hip arthroplasty (HTA). The position of the acetabular component depends on the orientation of the bony acetabulum and on the position of the patient’s pelvis. Without computer assisted navigation system, it’s difficult to know precisely how the patient’s pelvis is oriented during surgery, which could lead to improper cup alignment. We propose a method to estimate the position of the anterior pelvic plane (APP) using intraoperatively available landmarks and a calibration table so that the orientation of the patient’s pelvic can be determined intraoperatively. Consequently the desired acetabular component orientation can be achieved relative to the estimated patient’s pelvic position.

Materials and Methods: (A) Reference coordinate systems for the acetabular component orientation
Based on the anterior pelvic plane(APP)[1] a reference coordinate system C_{APP} can be established as shown in Figure 1. The acetabular component orientation is then defined by the anteversion and inclination on this reference coordinate system as in Figure 1. But intraoperatively APP is not available since the bilateral pubic tubercles are not accessible without the fluoroscopic images or CT based navigation systems. Intraoperatively a second reference plane can be obtained by bilateral anterior
superior iliac and the hip joint center as shown in Figure 2. Accordingly a reference coordinate system $C_{IRP}$ can be determined. Obviously the two reference coordinate systems $C_{APP}$ and $C_{ARP}$ are correlated by a rotation of the angle $\gamma$ around the axis $x_{APP}$ as shown in Figure 2.

(B) Morphological study of hips and construction of calibration curve
A morphological study based on a collection of 48 CT data set (Table 1) showed that there is a strong correlation between the ratio $L = L_{HJC\_ASIS}/L_{ASIS}$ and the angle $\gamma$. $L_{HJC\_ASIS}$ is the length of the vector connecting the hip joint center and the correspondent ASIS. $L_{ASIS}$ is the length of the vector connecting the bilateral ASIS as in Figure 2. This hints that L can be used to obtain an estimate $\gamma' = F(L)$ of the angle $\gamma$. The calibration curve $F(L)$ can then be constructed using the CT data as training samples. We applied two strategies to construct the calibration curve, (a) kernel density estimation (KDE) and (b) linear minimal mean square error estimator (LMMSE). Calibration curves computed from the 48 CT data are shown in Figure 3.

(C) Acetabular component orientation determination
For a specific patient, the reference coordinate system $C_{IRP}$ can be easily determined. The distances $L_{ASIS}$ and $L_{HJC\_ASIS}$ can be measured and therefore L can be calculated. The angle $\gamma$ can be estimated as $\gamma'$ using the calibration curves. Therefore the unknown reference coordinate system $C_{APP}$ can be reconstructed as $C_{RAPP}$ by rotating the $C_{IRP}$ by an angle $\gamma'$ as shown in Figure 2. The desired acetabular component orientation can be easily achieved in the reconstructed reference coordinate system $C_{RAPP}$.

Results: To verify the performance of the calibration curves, we carried out a leave-one-out verification of the two calibration curves. In this verification, we withdraw each of the 48 data set and use the left 47 data set to compute the calibration curves. We then use the calibration curves to estimate the angle $\gamma$ for the withdrawn data. We compare the leave-one-out experiment results with the case that no calibration curve is used and the mean value of $\gamma$ is used as the estimate for each data set. The result is shown in Table 2. The experiment result shows that the APP can be reconstructed with a moderate accuracy using the proposed approach. It’s also observed that the KDE based calibration curve performs better than the linear one.

To further verify the accuracy of the final acetabular cup orientation using our calibration curve, we carried out a leave-one-out evaluation on each CT data set using the calibration curve to simulate the operation procedure and then
checked the finally achieved inclination and anteversion. We set the desired inclination angle at 45° and anteversion angle at 20°. The result is shown in Table 3.

Table 3: Cross correlation between the style variables (interoperative vs. measurable) and related procedures

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Linear regression coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biopsy</td>
<td>0.1</td>
<td>0.05</td>
<td>0.5</td>
</tr>
<tr>
<td>Biopsy</td>
<td>0.2</td>
<td>0.07</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Table 3: Cross correlation between the style variables (interoperative vs. measurable) and related procedures

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Linear correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biopsy</td>
<td>0.1</td>
<td>0.05</td>
<td>0.5</td>
</tr>
<tr>
<td>Biopsy</td>
<td>0.2</td>
<td>0.07</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Figure 3: Relationship between the interoperative variables $P_{\text{inter}}$ and the measurable variables $P_{\text{meas}}$. The $P_{\text{inter}}$ variables are defined as the mean of all interoperative measurements. The $P_{\text{meas}}$ variables are defined as the mean of all measurable measurements. The trend line is calculated based on the linear regression model.

Figure 4: Relationship between the interoperative variables $P_{\text{inter}}$ and the measurable variables $P_{\text{meas}}$. The $P_{\text{inter}}$ variables are defined as the mean of all interoperative measurements. The $P_{\text{meas}}$ variables are defined as the mean of all measurable measurements. The trend line is calculated based on the linear regression model.
Discussion: Based on a morphological analysis of the hip anatomy using a collection of CT data set, a calibration table is constructed. Using the calibration table, the anterior pelvic plane can be estimated from a clinically available reference plane. The desired acetabular cup orientation can then be achieved in the reconstructed reference coordinate system using the estimated anterior pelvic plane. Experiments on the CT data set showed the performance of the proposed approach.

References


Assessment Of Accuracy Of Acetabular Cup Orientation In CT-free Navigated Total Hip Arthroplasty

FUKUNISHI S, FUKUI T, NISHIO S, YOSHIYA S

Department Of Orthopaedic Surgery Hyogo College Of Medicine, Nishinomiya, Japan

f9457@hyo-med.ac.jp

Introduction: In total hip arthroplasty (THA), component malpositioning can lead to increased risk of postoperative complications such as dislocation and polyethylene wear. A computer-assisted navigation system is expected to help to achieve accurate and reproducible alignment of the implant in relation to the bony morphology. We have used the OrthoPilotTM (B/BRAUN-Aesculap, Germany) CT-free navigation system to assure the improved acetabular cup orientation. In this system, a cup orientation is assessed with respect to the bony configuration as determined by palpation of the anatomical landmarks. However, evaluation of the cup orientation can be variable based on the reference system adopted in the analysis. In this study, intraoperative cup orientation as presented by the OrthoPilotTM navigation system was compared with the values obtained by postoperative radiological assessment using CT DICOM data and MIPAV (Medical Image Processing Analysis and Visualization) after navigate THA.

Materials and Methods: Patient selection: Since 2005, we have used the OrthoPilotTM CT-free navigation system for positioning cup in primary THA. Among the cases, 50 consecutive hips with both intraoperative and postoperative alignment data (based on navigation system and CT evaluation) were included in the study. Sequential process of the navigation: Preoperatively, a plain A-P pelvic radiograph was taken with two makers onto the bilateral anterosuperior iliac spines. These two makers are used to indicate the location of the bony landmarks both in intra- and postoperative evaluations. As the anatomical landmarks, the bilateral anterosuperior iliac spines and the upper margin of the symphysis were located and orientation of the pelvis was determined. The reference plane in the analysis was based on the triangle determined by these three landmarks. The angles of inclination and anteversion were calculated in...
Total Hip Replacement

relation to this reference plane. Surgical technique: Surgeries were performed with the same routine techniques for all patients. All THAs were performed with cementless cup (Plasma cup BTM, B/Braun-Aesculap, Germany) and stem (BicontactTM, B/Braun-Aesculap, Germany). For the cup positioning, the desired inclination and anteversion angles were set within the “safe zone” proposed by Lewinnek. We decided the anteversion of the cup under 10 degree in five cases of the high aged patients with the severe sagittal pelvic malrotation. Postoperative CT evaluation: Post operative CT was taken with the two makers onto the bilateral anteriosuperior iliac spines with the patient in the same position as that at the registration. A helical CT scanner was taken providing images with 2-mm slice intervals. The CT data was transferred as DICOM files to desktop computer. The DICOM data were recognized by MIPAV application for specification of the three-dimensional coordinate. The three anatomical landmarks were specified as the reference points according to the location of the markers observed in the CT images. Additionally, three points at the periphery of the cup were located on the images for determination of the three-dimensional cup orientation. The true radiological anteversion and inclination were calculated in the software.

Results: In the intraoperative evaluation, the mean inclination angle as determined with the navigation system was 44 ± 4° (range: 39.9 to 46.6°) after the final implantation. On the other hand, the mean inclination angle determined by calculation using the MIPAV was 45 ± 5° (range: 38.1 to 55.0°) postoperatively. The values obtained by both intra- and postoperative assessments corresponded well, and a discrepancy of more than 5° was observed only in one hip. As for the anteversion, the mean intra- and postoperative values were 11 ± 3° (range: 0 to 17.8°) and 13 ± 3° (range: 5.1 to 21.6°). A discrepancy of more than 5° was observed in one case, again, showing good agreement. In a comparison of the intra- and postoperative anteversion values in each case, postoperative value was higher than the intraoperative value in 42 of the 50 cases (84.0 %). Mean difference between the intra- and postoperative were 1 ± 4.8° and 2 ± 5.1° for inclination and anteversion respectively.

Discussion: Computer-assisted navigation system has been introduced to achieve desirable alignment of the implant in THA. Among the systems used in practice, CT-free navigation has a clear advantage of avoidance of preoperative examination associated with radiological exposure. However, its accuracy and reproducibility are concerns because the three-dimensional alignment is determined base on the anatomical landmarks located by palpation. They have used calculation methods, which were reported by Pradhan or Murray.
However, these methods are not satisfied the radiographic cup definition with same plane at intraoperative registration. In this study, good agreement between the intraoperative values presented by the navigation system and those in postoperative CT evaluation was observed, and validity of this navigation system was thus confirmed.
Acetabular Center Axis: A Novel Alternative To Anterior Pelvic Plane

HAKKI S

Department Of Orthopedics, Baypines Health Care, Florida, USA

stephanie.coleman@va.gov

Introduction: There is significant variation in registering anterior pelvic plane (APP) among experienced navigated hip surgeons reflecting negatively on the accuracy of determining inclination and anteversion. Whether it is variations in pelvic anatomy or improper positioning, this inaccuracy highlights the need for alternative methods of registration of which the acetabular center axis (ACA) is proposed. CT scan compared accuracy of ACA and APP in determining acetabular and cup anteversion and inclination.

Materials and Methods: The APP and ACA were defined and registered in 40 consecutive navigated total hip arthroplasty (THA) patients. Time was spent to ensure the registration of APP plane was as accurate as could be by carefully securing the positioning of the patient and ensuring the equidistance between the registration point on the skin and the APP bony landmarks. Postoperative CT scan measurements of acetabular and cup inclination and version angles were independently observed and compared with ACA and APP registration data using t-student test analysis. The data were also compared, in sub-groups of normal, protrusio and dysplastic hips.

Results: Mean anatomic (CT-scan) acetabular Version of all groups (ie Control) was 19.1(S.D. ± 5.8), 21.1(S.D. ± 8.2) in ACA software, and 17.5(S.D. ± 9.6) in APP software. This reflects reliably of ACA software in identifying the version of the acetabulum.

Cup implant Version(CT-scan) of all groups was 22.15(S.D. ± 8.7), 22.5(S.D. ± 4.2) in the ACA software and 17.1 (SD ± 8.6) in the APP software. This reflects reliably of ACA software in identifying the Version of the cup implant, although the ACA software seems more accurate.

Similarly in the normal group (arthritic hips with no protrusio or dysplasia), the
anatomical (CT scan) Version was 17.8(SD ±5.74), 19.9 (SD ± 8.6) in ACA and 13.9 (SD ± 7.4) in APP software.

The Version in the protrusio subgroups were: the anatomical (CT scan) Version was 25.0º (SD ± 9.5), in ACA= 25.0º (SD ± 8.5); and 24.3 (SD ± 9.1) in APP software.

The Version in dysplastic group were= 22.0 (SD=±6.1)in anatomic CT scan, 26.5 (SD ± 5.2) in ACA and 27.8 (SD ± 5.3) in APP software.

This showed no statistical difference in all and sub-groups, denoting accurate ACA software in detecting acetabular anatomy and cup orientation(p=0.96) (average difference in angle 0.15 degrees).

As for the mean anatomic (CT-scan) cup Inclination angle of all groups was 42.3º (S.D.±3.7), 40.9º(S.D. ± 4.6) in ACA software , and 41.3º(SD= ±3.0) in APP software.

In the normal group, the anatomic cup inclination angle was 40.3(S.D± 6.9), ACA inclination of 41.6(SD ±3.8) (p=0.27) and 42.2 (SD±3.6) ( P= 0.29) for APP software.

In the PROTRUSIO sub-group inclination angle was 41.3 (SD ±3.8); 45.3 (SD ±7.4)in ACA and 41.3 (SD± 5.0) for APP software(P= 1.0).

In the dysplastic subgroup the anatomic cup inclination angle was 43.3(SD =±5.0); 32.3 (SD±9.3) ( P = 0.08) for ACA and 40.0 (SD±4.0) for APP software. ( P= 0.34).

This showed no statistical difference in all and sub-groups, denoting accurate ACA software in detecting acetabular anatomy and cup orientation(p=0.61). However, both methods are within safety zone of Lewinnek.

Discussion: Inaccessibility of ASIS, variability of pelvic anatomy and change of its position during APP registration lead to cup orientation inaccuracies. This we tried very hard to avoid in this study to be able to accurately compare with the new ACA software that relies on readily palpable acetabulum irrespective of pelvic position. Post operative CT scan of the pelvis was used as a control to compare both software. Similar to the APP software, ACA software can accurately identify the cup orientation intraoperatively, but supersedes the APP software that it is easier to register and it is independent on the pelvic position changes that may occur intraoperatively.

We observed a great anatomical version range from 6 degrees to 30 degrees of anteversion of the acetabulum. While the anatomic inclination angle was about 47º ± 4º , we elected to keep the cup at less that 45º of abduction in all cases. Post-operative CT scan analysis indicates that Acetabular Center Axis (ACA) is a reliable software in identifying the cup version and inclination angles in navigated hip replacement.
Antero-lateral Subgluteal Mini-invasive Navigated Hip Replacement

HAKKI S

Department Of Orthopedics, Baypines Health Care, Florida , USA

stephanie.coleman@va.gov

Introduction: Purpose of mini-invasive hip arthroplasty, is least damage to skin and muscles. Unlike Roettinger modification to Watson-Jones, our approach requires no special table or instruments. Besides, direction of skin incision is perpendicular to interval between glutei and tensor muscles, thus called a Crisscross Approach. Incision is at direction of retractors causing less skin damage; and parallel to femur allowing expansion. No tendon or muscles are severed achieving a true inter-muscular non invasive approach. Unlike anterior approach, femoral circumflex vessels and lateral femoral cutaneous nerve are spared.

Materials and Methods: After working with 3 cadavers to perfect technique, 40 prospective patients underwent mini-invasive crisscross technique since December 2006. A standard non-cemented hip was implanted. Previously disrupted hip muscles patients were excluded. In the operating room, patients were secured in a lateral decubitus position using a Montreal board and pegs or other alternative with the pelvis flexed at 20°-30°. This will allow the operated leg to extend beyond the table to be placed in a standard plastic bag used routinely for all hip replacement. The anterior superior iliac spine (ASIS), the greater trochanter (GT) and its tubercle are identified and marked. A line is drawn between ASIS and GT tubercle representing the interval between the glutei and the tensor fascia lata muscles. Another line representing the skin incision is drawn perpendicular. It may be curved a little toward the femur starting two inches inferior and posterior to ipsilateral ASIS extending distally for 3 inches or more for obese or muscular patients. The Crisscross Approach starts with a skin incision being made as above and through the subcutaneous fat identifying the inter-muscular interval between the glutei and the tensor fascia lata. Sharp dissection is made in the connecting fascia only and blunt dissection is needed to separate the two muscles. A branch of the superior
gluteal nerve proximally crossing from the glutei to the tensor fascia lata may be encountered but it should not be disturbed as long as blunt dissection is maintained. Curved retractors are placed one above and the other below the femoral neck exposing the anterior capsule. Incision/ or excision is made in the capsule and the retractors are re-placed to better expose the femoral neck. The appropriate level of neck is osteotomized and the head is extracted as routine. Acetabulum is further exposed by placing the curved retractors at about mid anterior and mid posterior. Acetabulum is cleaned from soft tissue and reamed as routine. The final appropriate cup size and orientation is implanted routinely. Before exposing the femoral canal the deep fascia at the junction of the glutei and the vastus lateralis should be incised (about 2-3 inches). This will tremendously help femoral canal exposure. Then the surgeon is positioned anterior, the patient is made fully paralyzed and the table is tilted 20°-30° posteriorly (away from the surgeon). Hip extended 20°-30°, externally rotated to 80°-90° and adducted with a retractor underneath femoral neck and a curved one on greater trochanter to protect the glutei. Leg is allowed to drop in a bag (posteriorly). The assistant holding the leg posteriorly may elect to sit on a stool while doing so. Broaching or reaming and final implant insertion as routine. Canal finder is helpful to avoid going through the cortex. Final trial stem and head is reduced and the hip is taken through routine range of motion to assess stability. Then the final femoral implant is inserted. Posterior capsule need not be disturbed; however, the superior and inferior capsule should be detached from the neck to allow better exposure of the femoral canal. Closure starts with one or two stitches in the remainder of the capsule if any left, then the deep fascia at the junction of glutei and vastus lateralis with absorbable suture. Finally, subcutaneous fat and skin are closed as routine.

Results: There was no major neurovascular damage or complications related to this exposure. Follow up to a maximum of 14 months revealed no deep infection and no dislocation or fracture. We undersized three stems out of 40 at the beginning but that did not require re-operation. Surgery time averaged 15 minutes longer but that was reduced as we gained experience. Cup position was navigated and postoperative CT scan confirmed satisfactory cup and stem position. One case that had an undersized prosthesis settling to about half an inch short which required a 3/8 inch insole for the patient to wear. Rehab goals were met after 4 sessions in all 40 patients. Patients were allowed to go home on two crutches in 2-3 days. Full weight bearing was allowed in 3-4 weeks. No limping noted at 3 months follow up perhaps attributed to muscle being severed. One patient had limping due to a shorter operated leg from under sizing of femoral stem.
**Discussion:** Crisscross approach differs by transecting no tendon or muscles, requiring no special table or instruments with incision parallel to femur facilitating expansion and reducing skin damage resulting in true non-invasive approach.

**References**

1 - Anerolateral Mini-incision Hip replacement Surgery, A modified Watson-Jones Approach, Kim C. Bertin, MD; and Heinz Rottinger, MD, CORR #429 PP 248-255, 2004

2 - Minimally Invasive or Limited Incision Hip Replacement Classification, Clive P. Duncan, MD, FRCSC, CAOS INT’L 2007

3 - Total Hip Arthroplasty Through a Minimally Invasive Anterior Surgical Approach; Robert E. Kennon et al
Intraoperative Soft Tissue Tension In Total Hip Arthroplasty Using CT-based Navigation System

HANANOUCHI T, NISHII T, SAKAI T, TAKAO M, TSUDA K, YOSHIKAWA H, SUGANO N

Department Of Orthopaedic Surgery, Osaka University Graduate School Of Medicine, Suita, Japan

hana-osaka@umin.net

Introduction: In total hip arthroplasty (THA), it has been reported that three-dimensional preoperative plan and navigation system allow us to adjust the leg length of lower limb as well as favorable alignment of prosthetic components. In this case, soft tissue tension around the hip joint, which is evaluated by intraoperative traction of the lower limb, is not probably same. To the best of our knowledge, it is not clear how long the soft tissue tension is when adjusting the leg length of lower limb. In addition, the effect of the soft tissue tension on intraoperative or postoperative clinical outcome has not been well discussed. The purpose of this study was to measure the soft tissue tension around the hip joint and to investigate the correlation between the soft tissue tension and intraoperative or postoperative hip range of motion (ROM), and intraoperative distance for the adjustment of the limb length inequality.

Materials and Methods: We investigated 71 patients who underwent primary THA with the measurement of intraoperative soft tissue tension and ROM in and between January 2005 and December 2006. All THAs of enrolled patients were included in adjustment of the limb length inequality. They consisted of 45 unilateral osteoarthritic patients and 26 bilateral osteoarthritic or osteonecrotic patients who previously underwent contralateral THA. The mean age of the patients was 57.0 years (range, 22-79 years). They included 9 men and 62 women. Preoperative ROMs (flexion and abduction) of the patients were measured by a physical therapist with the blind of this study. The three dimensional planning for both components was performed with CT scan images of the pelvis and the femur. Using the CT based navigation system, we performed THA on the basis of the preoperative planning. After the implant
fixation of both components, we measured the separation distance of the hip joint between the center of the cup and the center of femoral head while maximum distal traction of low limb. The CT based navigation system presented the separation distance on the monitor, but “0 mm” when the separation distance was less than five mm. We divided their patients into two groups; Group 1, “the separation distance was less than five mm” and Group 2, “the separation distance was at least five mm”. We also measured intraoperative ROMs and distance for the adjustment of leg length of lower limb. Postoperative ROMs one year after surgery were measured in the outpatient clinic. We investigated whether they had postoperative dislocation one year after the surgery. In order to investigate the effect of the soft tissue tension on clinical outcome, we compared intraoperative and 1-year postoperative measurements between the two groups.

**Results:** The number of patients in Group 1 and 2 was 17 and 54 respectively. The mean separation distance in Group 2 was 9.0 mm (range, 5 to 19 mm). The average preoperative ROMs in Group 1 were 86 (SD; 21) degrees for flexion and 16 (SD; 11) degrees for abduction. The average preoperative ROMs in Group 2 were 87 (SD; 21) degrees for flexion and 17 (SD; 9.1) degrees for abduction. There was no significant difference between the groups. On the contrary, the average intraoperative ROMs in Group 1 were 83 (SD; 11) degrees for flexion and 19 (SD; 8.0) degrees for abduction. Then, the average intraoperative ROMs in Group 2 were 92 (SD; 14) degrees for flexion and 33 (SD; 8.5) degrees for abduction. There was statistically significant difference between the two groups.

The mean intraoperative distance for the adjustment of the limb length inequality was 14 (SD; 5.0) mm in Group 1 and 10 (SD; 6.7) mm in Group 2. There was also statistically significant difference between the two groups. The average postoperative ROMs in Group 1 was 104 (SD; 14) degrees for flexion and 35 (SD; 6.0) degrees for abduction. While, the average postoperative ROMs in Group 2 was 113 (SD; 11) degrees for flexion and 37 (SD; 4.2) degrees for abduction. There was no significant difference in abduction between the groups. However, there was statistically significant difference in flexion between the two groups. There was no case of the dislocation in both groups one year after the surgery.

**Discussion:** When using the CT-based three dimensional planning and the navigation system for the adjustment of the limb length inequality, the soft tissue tension has relatively large variation from 0 to 19 mm. The soft tissue tension is negatively correlated with the distance for the adjustment of the limb
length inequality, and affects intraoperative ROMs of the hip. Furthermore, the soft tissue tension also affects one-year postoperative ROM of flexion although the difference between the two groups was about ten degrees.
Cup And Stem Navigation In THA With Only One Pelvic Tracker - Technique And Preliminary Results

KIEFER H, SCHMERWITZ U

Lukas Hospital, Buende, Germany

hartmuth.kiefer@t-online.de

Introduction: After the introduction of cup navigation in 2001, this image free technology is also available for complete THA navigation for optimal implant positioning since 2004. However, for this procedure the application of a femoral rigid body to the greater trochanter is necessary. In minimal invasive anterior or anterolateral approaches this might be problematic due to too little space. To solve this problem, the navigation software “Orthopilot THAplus” was developed in 2007. Even though this software only needs one pelvic sensor that collects data about the cup position, it reveals intraoperative data about the prospected changes of leg length and femoral offset.

Materials and Methods: 40 Patients suffering from primary coxarthrosis were surgically treated using navigation technology with a cementless Plasmacup/Bicontact THA system combined with Biolox Delta ceramic couplings. The image free navigation system Orthopilot with the software „THAplus”, which needs only one bone fixed tracker at the pelvis, was used. After pelvic registration, the initial leg length and femoral offset are registered. Therefore the patella’s middle and a marked point at the greater trochanter are palpated with a sensor armed pointer. After cutting the femoral neck, the acetabulum is prepared and the cup is placed, using the well established and proven cup navigation procedure. After broaching the femur with a rasp (i.e. trial stem) in place, the easily reproducible points, described above, are palpated again. Based on this data, informations about the expected changes of leg length and femoral offset are calculated and depicted at the monitor. This can influence the decision for the selected final position and implants. The final result is then monitored and documented again. For the evaluation, intraoperatively monitored navigation system generated data was compared to measurement values from standardized plain pelvic x-rays.
Results: On all 40 patients, the described surgical technique was used via a small surgical approach. Interruptions or complications were not reported. 95% of the cups were found to be within the safe zone (Lewinnek). Except for two outliers the changes of leg length measured from x-rays and calculated by the navigation computer matched very well (average 4.4mm difference). Since interpretation of the femoral offset on the x-ray projection is difficult, the obtained values can hardly be compared to the calculated data from the navigation system. A clear tendency towards medialisation was found, because in cases of coxa vara or lateralized hip centers the offset reduction could not be completely compensated by the stems due to their geometrical design. However, the changes of the femoral offset matched well with the judgment of the surgeon as well as with the intraoperative fluoroscopic controls.

Discussion: In comparison to fully navigated THA, using the “Orthopilot THAplus” version does not allow intraoperative calculation of the final range of motion. But besides this lack of information changes of the leg length can be calculated with fairly high accuracy. This is possible with the use of only one pelvic fixed sensor, which is used for the standardized cup navigation anyway. While the comparison of navigation data concerning leg length change matches radiologic measurements, this is not true for the femoral offset. The offset data obtained from x-rays seems to be more inaccurate because of projection errors. Thus the intraoperative calculated change of the femoral offset seems to be superior.

Using the navigation software “Orthopilot THAplus”, cup and stem navigation can be performed with small surgical anterior approaches. The precision of the cup position and the prediction of the changes of femoral length and offset is high compared to the complete THA navigation technique. This advantage of the need of only one bony fixed pelvic sensor is tied to the lack of information about the final ROM.

References
5. Kiefer H, Othman A. The Orthopilot navigation system for primary Bicontact THR. Z Orthop Unfall 2007; Suppl 1: 49-52
Evaluation Of The Clinical Accuracy Of A CT-based Navigation For Femoral Stem Orientation And Leg Length Discrepancy

Kitada M1, Nakamura N1, Sugano N2, Kakimoto A1, Iwana D1, Nishii T3, Miki H3

1 Center Of Arthroplasty, Kyowakai Hospital, Japan
2 Department Of Orthpaedic Surgery, Osaka University Graduated School Of Medicine, Japan
3 Department Of Orthpaedic Surgery, Osaka Medical Center, Japan

m-kitada@umin.net

Introduction: Component malpositioning and postoperative leg length discrepancy are the most common technical problems associated with total hip arthroplasty. As navigation was supposed to offer the potential to reduce the incidence of these problems, there were many reports about the accuracy of a CT-based navigation. Though most of these referred to the cup orientation and the leg length discrepancy, only a few analyzed that of femoral stem in detail. So our purpose was to examine the accuracy of the femoral stem orientation and the leg length discrepancy under the precise use of the CT-based navigation.

Materials and Methods: Of all patients who underwent total hip arthroplasty with CT-based navigation system (Stryker-Leibinger, Freiburg, Germany) in our hospital, we analyzed 20 hip joints of 15 patients (female 16 joints, male 4 joints, average age 57.3 years old) who could be measured implant orientation and leg length discrepancy by postoperative CT. We operated all joints with posterolateral approach. Femoral tracker was rigidly fixed on the greater trochanter by a triangular plate and pelvic tracker was on the ilium by two 4mm-Apex pins. Both trackers were checked not to displace through the operation by the verification points which were set separately. The anteversion and valgus angles of the femoral stem (CentPillar, Stryker), the anteversion and inclination angles of the cup and the leg length difference were measured on the postoperative CTs, using a preoperative planning module of the same
navigation system. The accuracy of the cup orientation was measured to use as the control of that of the femoral stem. Each parameter was compared by paired t-test and ANOVA for statistical analyses.

**Results:** The postoperative position of the stem was $31.1 \pm 12.7$ (3 to 49) degrees of anteversion and $0.35 \pm 1.5$ (-2 to 4) degrees of valgus and the position of the cup was $20.8 \pm 8.1$ (3 to 31) degrees of anteversion and $40.8 \pm 3.5$ (35 to 48) degrees of inclination, while the intraoperative angles which were recorded by navigation system were $31.8 \pm 13.3$ (2 to 58), $-0.5 \pm 2.5$ (-5 to 4), $20.5 \pm 6.1$ (10 to 29), and $41.0 \pm 2.2$ (36 to 45) degrees. Between postoperatively and intraoperatively, each parameter was not statistically differed (paired t-test). The differences of each parameter were $0.7 \pm 4.1$ (-7 to 10), $-0.9 \pm 2.1$ (-5 to 3), $-0.3 \pm 4.7$ (-6 to 8), and $0.2 \pm 2.6$ (-6 to 4) degrees and there is also no statistical difference among these four groups (ANOVA). The leg length discrepancies were $3.2 \pm 6.1$ (-14 to 10)mm on postoperative CTs and $2.7 \pm 5.9$ (-12 to 14)mm in the navigation records. The absolute values of the differences of these were $2.9 \pm 3.5$ (0 to 12)mm.

**Discussion:** There were many reports about the accuracy for cup orientation which were assisted by image or non-image based navigation systems and the most of them came to result in a good accuracy. However, we could find few reports about femoral stem orientation in detail [1]. We selected all 20 joints in this study that displacement of the both pelvic and femoral tracker did not occur intraoperatively. Considering the errors that must occur when taking the reference points on the postoperative CT, we measured the orientation of the cup in the same way and use the accuracy of it as an internal control. As a result, the accuracy of the femoral stem was good and not statistically different with that of the cup. But considering the acceptable range of each parameter, the difference of the valgus angle of the stem could not be enough. As for the accuracy of the leg length discrepancy, it was smaller than previous reports [2, 3] and practicable for intraoperative adjustment.

Conclusion: When using the CT-based navigation system precisely, the accuracy of the stem orientation was as good as that of the cup orientation and leg length adjustment seemed to practicable.

**References**

Possible Registration Error For The Anterior Pelvic Plane And Its Effect On Inclination And Antversion Calculation In Navigated THR - A Sawbone Study

MATTE T, DECKING R, OSTERTAG O, REICHEL H

Orthopedic Department, University Hospital, Ulm, Germany

thomas.mattes@uni-ulm.de

Introduction: Anterior pelvic plane is an accepted reference plane for calculation of cup inclination and anteverision during navigated THR. Accuracy is dependent on probing the bony anatomical landmarks on the symphysis tubercle (ST) and the anterior superior iliac spine (ASIS). Soft tissue over the landmarks may complicate probing the exact bony point. Some systems or surgeons consider probing the landmarks on the skin surface as adequate others demand ultrasound detection for more accurate detection. We examined the error on inclination and anteverision of the cup in navigated THR by given referencing errors to give an impression of the possible intraoperative deviation of the calculated to the true values of cup inclination and anteverision.

Materials and Methods: After referencing the anterior pelvic plane of a sawbone model probing the ASIS on both sides and the ST on one side an ACA screwing cup size 54 (Zimmer, Warsaw, Indiana) was implanted in the left acetabulum of the sawbone using the Navitrack navigation system (Zimmer, Warsaw, Indiana). The model was prepared with precision drillings on the ASIS and TR. In drill holes screws with a measuring point for the pointer in the head has been inserted. The position of the screws reflecting a registration error has been changed in 5 mm steps using washers. In unchanged position of the implanted cup a re-referencing has been performed in 5 mm steps up to 30 mm for each landmark alone and in crossed and parallel combination. The change of anteverision an inclination related to the “new anterior pelvic plane” was given from the navigation software.
Results: Maximum and minimum value for inclination was 47° respectively 42° implying an error range of 5°. Maximum anteversion amounted 17°, lowest value was 4° (range 13°). For inclination maximum error was seen for simultaneous raising of ASIS an unchanged TR. For anteversion unilateral raising of the ASIS anteriorly of the opposite side cause the greatest error. Each step of a 5 mm reference error caused an anteversion error of about 1°. For inclination a probing error of 10 mm gives an inclination error of about 1°. A medialisation or lateralisation of the TR up to 30 mm doesn’t change the calculated cup angles. Highest summation of inclination and anteversion error was 9° (inclination of 47° in combination with 17° anteversion.

Discussion: The study showed an expected error of 2° in calculation of inclination despite a possible probing error of 10 mm and of anteversion for a probing error of 5 mm. For clinical use an error up to 2° is negligible in our opinion. Higher mismatches during probing may be critic, but from clinical experience unlikely using bony landmarks. Probing landmarks on skin surface with (partial) compression of subcutaneous fat tissue may cause higher reference errors and should be avoided. Probing anatomical landmarks with a sharp as pointer on bony surface allows a precise calculation of the reference plane for cup inclination and anteversion using the Navitrack navigation system. More sophisticated techniques for detecting the ASIS and TL landmark as Ultrasound are therefore not necessary.
Accuracy Of The Cup Orientation With Minimally Invasive Total Hip Arthroplasty Compared To Conventional Total Hip Arthroplasty Using CT Free-navigation System

NISHIO S, FUKUNISHI S, FUKUI T, YOSHIYA S

Department Of Orthopaedic Surgery, Hyogo College Of Medicine, Japan

shoji624@hyo-med.ac.jp

Introduction: There is ongoing discussion about the potential benefits and risk of minimally invasive technique in THA. There are increased risks, malpositioning and fixation errors in the MIS THA. Navigation system is expected to help to achieve accurate alignment of the implants. In this study, we evaluated the cup positioning after MIS and conventional approach in CT-free navigated THA.

Materials and Methods: Patient selection: Since 2005, we have used the OrthoPilot™ CT-free navigation system for positioning cup in primary THA. Among the cases, 50 consecutive hips with both intra-operative and post-operative alignment data (based on navigation system and CT evaluation) were included in the study. We retrospectively evaluated with three type of the approaches, including 10 cases with conventional Hardinge (CH) approach, 30 cases with MIS modified Hardinge (MH) approach with a skin incision of 8 cm or less and 10 cases with Modified Watson-Jones (MW) approach. Surgical technique: The THAs were performed with the same routine techniques for all patients using OrthoPilot™ CT-free navigation system. All THAs were performed with cementless cup (Plasma cup B™, B/Braun-Aesculap, Germany) and stem (Bicontact™, B/Braun-Aesculap, Germany). For the cup positioning, the desired inclination and anteversion angles were set within the “safe zone” proposed by Lewinnek. We decided the anteversion of the cup under 10 degree in five cases of the high aged patients with the severe sagittal pelvic mal-rotation. Postoperative CT evaluation: A helical CT scanner was
taken providing images with 2-mm slice intervals. The CT data was transferred as DICOM files to desktop computer. The DICOM data were recognized by MIPAV (Medical Image Processing Analysis and Visualization) application for specification of the three-dimensional coordinate. The three anatomical landmarks were specified as the reference in the CT images. Additionally, three points at the periphery of the cup were located on the images for determination of the three-dimensional cup orientation. The true radiological anteversion and inclination were calculated in the software.

**Results:** There was no infection and dislocation case in three groups. In the intraoperative evaluation, the average of inclination angle as determined with the navigation system was 43.3° (range: 41 to 48°) of the CH approach, 42.8° (range: 38 to 47°) of the MH approach and 43.0° (range: 39 to 46°) of the MW approach after the final implantation. On the other hand, the average of inclination angle determined by calculation using the MIPAV was 44.3° (range: 39.9 to 47.6°) of the CH approach, 43.7° (range: 39.0 to 52.0°) of the MH approach and 43.5° (range: 40.2 to 47.6°) of the MW approach postoperatively. As for the anteversion, the average of intra- and postoperative values were 12.7° (range 0 to 20°) and 15.5° (range: 5.1 to 21.6°) of the CH approach, 11.4° (range: 0 to 16°) and 13.4° (range: 5.1 to 22.4°) of the MH approach and 16.1° (range: 15 to 17°) and 17.3° (range: 15.5 to 20.4°) of the MW approach. The values obtained by both intra- and postoperative assessments corresponded well in all approaches. There was no significant difference with three approaches. Additionally, a discrepancy with the intra-operative inclination and post-operative inclination of more than 5° was observed only one hip in MH approach. A discrepancy with intra- and postoperative anteversion of more than 5° was observed one case in CH approach, again, showing good agreement.

**Discussion:** MIS THA may offer many potential benefit, such as shorter post operative recovery times, less pain, less post operative blood loss, and better cosmetic appearance. However, opponents of MIS argue that it lead more complications, mainly due to poor operative visualization. Especially, Implant malposition can lead to increased risk of postoperative complications such as dislocation and polyethylene wear. We hypothesized that navigation system may be helpful for MIS THA. In this study, we compared accuracy of cup positioning with three approaches. MH approach so called Mini-one approach is showing shorter incision and better cosmetic appearance, but one third of gluteus medius must split in this MIS approach. On the other hand, another MIS approach, MW approach was developed using intermuscular plane between tenser fascia lata and gluteus medius. It does not need to split gluteus medius,
but this new approach reveals poor visualization. We commonly used CH approach for the primary THA in the past. We started MIS THA methods at 2005, and at the almost same time, we started using CT-free navigation system. It might be expected that we need the learning curve for good agreement of the clinical results with MIS THA. However, cup positioning of MIS THA in combination with CT-free navigation system revealed successful date in this study, there was no significant difference with three approaches including MW approach. A solution to the poor operative visualization is to consider using MIS in combination with computer navigation.
Leg Length And Offset Measurements In Imageless Stem Navigation During Total Hip Arthroplasty - An Experimental Cadaver Study

RENKAWITZ T, SENDTNER E, GRIFKA J, KALTEIS T

Department of Orthopaedic Surgery, Regensburg University, Germany

t.renkawitz@asklepios.com

Introduction: Pain relief and restoration of hip biomechanics are the desired goals in performing total hip arthroplasty. In order to optimize function, hip mechanics should be restored to as near normal as possible. This includes restoration of leg length as well as femoral offset. The hip acts as a fulcrum between the bodyweight and the abductor mechanism. Medialization of the hip’s center of rotation decreases the moment arm for body weight, increasing the femoral offset lengthens the lever arm for the abductor muscles. Marked leg length discrepancy has been associated with abnormal force transmission across the hip joint and reduced patient satisfaction. Femoral offset correlates with hip abduction motion, abductor muscle strength and the rate of polyethylene wear. However, determining leg length and offset changes intraoperatively in primary total hip arthroplasty remains a challenge. We asked whether the intraoperative assessment of leg length and offset would be accurate and reliable using an imageless navigation system during total hip arthroplasty using cadaver specimens.

Materials and Methods: Screws were inserted as fiducial landmarks into the pelvis and femur. Pre- and postoperatively, all specimens were CT scanned. Total hip arthroplasty was then performed in eighteen cadaver specimen hips using an imageless navigation system (VectorVision hip 5.0 unlimited, BrainLAB, Feldkirchen, Germany). A standard lateral, transgluteal (Bauer) approach was used. Press-fit acetabular components (Pinnacle, DePuy, Warsaw, Indiana, USA), standard cement-free hydroxyapatite-coated stems (Corail, DePuy, Warsaw, Indiana, USA) and 28-mm and 36-mm Biolox® Delta ceramic heads (DePuy, Warsaw, Indiana, USA) in head lengths from +1 to +5mm were
used. The so called leg situation algorithm of the navigation system guides the surgeon to return the femur into the exact same neutral orientation it was in before reconstruction. Once the leg is within +/- 5° of that initial position the change in leg length and offset is displayed. Difference between leg length/offset change measured on the CT scans and calculated by the navigation system was analyzed. A new control method using specific CT analysis software allowed us to simultaneously visualize and measure the true pre- and postoperative leg length and offset changes on CT scans. Comparison of the leg length and offset measurements made were made by two blinded examinators at two different measurement times

**Results:** There were no statistically significant differences between the leg length and offset changes measured on CT scans compared with the calculation method using the leg situation algorithm of the imageless navigation system respectively. The CT based control method showed a high inter- and intra-individual reliability when performed by two blinded investigators.

**Discussion:** Leg length and offset measures are reliable and reproducible in an experimental cadaver study using an imageless navigation system. The leg length situation algorithm offers the advantage of measuring leg length through determining the change in position of the femur relative to the pelvic coordinate system without the need to calculate the center of rotation of the hip joint. Further studies should now research into the accuracy and reliability of imageless stem navigation algorithms in a clinical setting.
Preoperative Planning For Total Hip Arthroplasty With CT Based Surgical Planning System

TAKAMATSU A, SATOH K

Department Of Orthopaedic Surgery, Nagoya Daini Red Cross Hospital, Nagoya, Japan
takira@nagoya2.jrc.or.jp

Introduction: Total hip arthroplasty (THA) is planned by applying a template sheet to plain radiographs, and a thorough evaluation of plain radiographs is necessary. However, accurate preoperative planning is sometimes difficult, especially in dysplastic hips. To achieve accurate preoperative planning, we have been using CT based templating since 2007. In this study, we report the results of our study of CT based preoperative planning of THA and its problem. The aim of this study was to evaluate the efficacy of CT based planning, compared with radiographic planning.

Materials and Methods: The subjects were 20 hips (20 patients) that were preoperatively planned on both plain radiographs (radiographic planning) and 3D-CTs (CT planning). The average age was 63.7 y.o. The 20 hips consisted of 15 hips with osteoarthritis and 5 hips with osteonecrosis of femoral head. 15 hips with osteoarthritis were divided into two groups by Crowe classification. The Crowe classification was Group I for 11 hips, Group II for 4 hips.

Results: In all cases, implant was Super secure fit HA coated stem and Triad HA cup (Striker). Hip OP surgical planning system which Dr. Toni developed was used for CT based planning. At first, CT images from acetabulum to femoral entire length on affected side is transfered to personal computer as DICOM data, and measuring matching size of CT image and implants, finally 3D-CT images can be reconstructed with implants. In radiographic planning, only one examiner who has speciality in hip surgery planned the size of cup and stem with applying a template sheet to plain photographs. In CT planning, another examiner who didn’t know the implanted size planned with Hip OP. The matching rate was defined to be the
rate of complete match between the planned size and the implanted size of the prosthesis, also the degree of difference (size over or under) was investigated.

Results: The matching rate of the cup was 73% by radiographic planning and 81% by CT planning. The matching rate of the stem was 64% by radiographic planning and 73% by CT planning. It means that both matching rates were higher by CT planning than by radiographic planning. In group I of Crow classification, the matching rate of the cup was 64% (7/11) by radiographic planning and 73% (8/11) by CT planning, while in group 2, it was 25% (1/4) by radiographic planning and 75% (3/4) by CT planning. In cup, 3 cases with radiographic planning and 2 cases with CT planning were 1 size over planned from the implanted size. 3 cases with radiographic planning and 4 cases with CT planning were 1 size under planned from the implanted size. In stem, 2 cases with radiographic planning and 1 case with CT planning were 1 size over planned from the implanted size. 2 cases with radiographic planning and 3 cases with CT planning were 1 size under planned from the implanted size. 2 size over planned size was showed in only one case with radiographic planning.

Discussion: CT planned sizes tended to be smaller than the implanted size, because it was difficult to find how overlapping of cortex on CT image and the implant on Hip OP was acceptable. The anteroposterior diameter of the acetabulum, the location of bone spurs and bone defects, and morphology such as the femoral anteversion angle could be more accurately evaluated by CT planning than by radiographic planning.

Conclusions: These results showed that the matching rate by CT planning for hips with Crowe 2 was higher than by radiographic planning. CT planning was more useful for accurate planning for severely dysplastic hips.
Are There Inert Radiographic Parameters On AP Pelvic Radiographs? A Computer-assisted Study

TANNAST M1, MISTRY S1, STEPPACHER SD1, SIEBENROCK KA1, ZHENG G2

1 Department Of Orthopaedic Surgery, Inselspital, University Of Bern, Switzerland
2 MEM Research Center, ISTB, University of Bern, Switzerland

moritz.tannast@insel.ch

Introduction: Recently, the correct interpretation of anteroposterior (AP) pelvic radiographs has regained increased attention, particularly in the field of joint preserving hip surgery. The diagnosis of acetabular retroversion associated with femoroacetabular impingement or hip dysplasia is made regardless the individual pelvic orientation due to the lack of a method of correction. Furthermore, it is known that a substantial number of the most common radiographical hip parameters can vary with the individual pelvic orientation. The goal of the study was to evaluate by means of a novel computer assisted method whether there are radiographic hip parameters exist that do not alter when pelvic x-rays area standardized to a neutral orientation.

Materials and Methods: Digital AP pelvic radiographs of 100 consecutive hips were used for evaluation. The blinded and randomized x-rays were examined by two independent observers with special software that has been validated previously. The software Hip2Norm is able to accurately correct the projected acetabular rim and the associated parameters for pelvic malpositioning based on a cone projection model1. The following parameters were investigated: femoral head coverage in craniocaudal and anteroposterior direction (in total and for each single quadrant of the femoral head), the lateral center edge angle, the acetabular index, the ACM-angle, the extrusion index, the cross-over sign, the retroversion index, and the posterior wall sign. All parameters were first measured regardless to the individual tilt and rotation. These non-standardized values were then compared to the standardized values for a neutral pelvic
orientation. This was defined with a pelvic inclination of 60 degrees which was detected with one single strong lateral pelvic radiograph.

**Results:** There were no differences in evaluation of the radiographs between the two observers concerning the significance of standardized and non-standardized values for the measured features. All but three parameters were significantly different when measured to the anatomically reference neutral orientation (Table).

The only parameters that did not change after standardization were the total femoral coverage, the acetabular index and the ACM.

<table>
<thead>
<tr>
<th>Radiographic Parameter</th>
<th>Absolute difference standardized / non-standardized</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total anterior coverage [%]</td>
<td>4.9 ± 4.0 ( -9.9 - 14 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Anterior cranio medial [%]</td>
<td>11.2 ± 10.4 ( -67.8 - 31.5 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Anterior cranio lateral [%]</td>
<td>4.8 ± 5.7 ( -45.1 - 23.2 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Anterior caudo medial [%]</td>
<td>3.2 ± 4.5 ( -20.8 - 24.5 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Anterior caudo lateral [%]</td>
<td>0 ± 0 n.d.</td>
<td></td>
</tr>
<tr>
<td>Total posterior coverage [%]</td>
<td>-2.5 ± 8.8 ( -34.3 - 27.5 )</td>
<td>0.006</td>
</tr>
<tr>
<td>Posterior cranio medial [%]</td>
<td>-2.3 ± 4.5 ( -44 - 10.2 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Posterior cranio lateral [%]</td>
<td>-8.1 ± 8.9 ( -40.4 - 48 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Posterior caudo medial [%]</td>
<td>-8.3 ± 8.9 ( -67 - 49.3 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Posterior caudo lateral [%]</td>
<td>0.1 ± 1.4 ( -8.3 - 11.9 )</td>
<td>0.661</td>
</tr>
<tr>
<td>Total crano caudal coverage [%]</td>
<td>-0.47 ± 2.8 ( -10.9 - 7.9 )</td>
<td>0.072</td>
</tr>
<tr>
<td>Anterolateral quadrant [%]</td>
<td>6.5 ± 6.9 ( -16.1 - 28.9 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Posterolateral quadrant [%]</td>
<td>-4.2 ± 5.0 ( -20.1 - 12.3 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Anteromedial quadrant [%]</td>
<td>0.6 ± 1.7 ( 0 - 11.2 )</td>
<td>0.022</td>
</tr>
<tr>
<td>Posteromedial quadrant [%]</td>
<td>-0.1 ± 0.6 ( -6.9 - 0 )</td>
<td>0.234</td>
</tr>
<tr>
<td>Lateral center edge angle [degrees]</td>
<td>-1.1 ± 1.68 ( -8.9 - 5.6 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Acetabular Index [degrees]</td>
<td>0.1 ± 1.9 ( -7.6 - 7 )</td>
<td>0.451</td>
</tr>
<tr>
<td>ACM-Angle [degrees]</td>
<td>0.1 ± 0.8 ( -1.5 - 4.3 )</td>
<td>0.595</td>
</tr>
<tr>
<td>Extrusion Index [degrees]</td>
<td>2.4 ± 3.9 ( -20.8 - 24.5 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>% of hips with positive cross-over sign (after standardization)</td>
<td>45% (29%)</td>
<td>0.013</td>
</tr>
<tr>
<td>Retroversion index [%]</td>
<td>6.8 ± 14.2 ( -69 - 53 )</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>% of hips with positive posterior wall sign (after standardization)</td>
<td>79% (63%)</td>
<td>0.009</td>
</tr>
</tbody>
</table>

As an example, the figure shows a 26-years old female patient underwent bilateral two-stage surgical hip dislocation for FAI treatment with trimming of the acetabular rim. The AP pelvic radiograph reveals an acetabular retroversion on the right side and a more or less normal configuration of the acetabular rim.
on the left side. After computerized correction to the neutral orientation of 60 degrees inclination, the cross-over sign on the right side disappeared. (AW = anterior wall, PW = posterior wall).

Discussion: Except from the ACM and the acetabular index, basically all parameters change when standardized to a neutral orientation. Although from a statistical point of view, the total craniocaudal femoral coverage did not change, it is likely that this is due to an inverse effect of the anterior and posterior part of the acetabulum. We conclude that the most common hip parameters can not be reliably measured without standardization. The proposed software Hip2Norm represents a useful tool for standardization to an anatomical neutral orientation. It remains to be proven that the standardization of the parameters correlates with the clinical symptoms.

References
Combined Native Hip Motions Strongly Demonstrate The Need For Navigation In Total Hip Arthroplasty

THORNBERY RL1, NELSON LS2

1 Florida State University, Tallahassee, FL, USA
2 Georgia State University, Atlanta, GA, USA

hthorny2@aol.com

Introduction: Total hip arthroplasty (THA) is one of the most successful medical interventions developed. Due to this success, basic research on native hip motions seems less imperative. However, recent literature on retrievals of hip implants suggests just the opposite. Reports of 60% of retrieved implants showed signs of impingement with 30% rated moderate to severe with a resulting doubling of the wear rate in these implants is disturbing.1 It is critical to completely understand the native hip range of motion to ensure incidences of implant impingement is minimal. This study was performed to examine all combinations of native hip motion. This information is necessary to accurately predict the probability of impingement in total hip arthroplasty and demonstrate a need for computer navigation.

Materials and Methods: Five fresh cadaveric specimens (71-94 years of age) were obtained and pre-screened with CT scans not to have significant osteoarthritis, hip dysplasia, femoroacetabular impingement syndrome or previous surgery. Range of motion was calculated in all ten intact specimen hips and four of the specimens were dissected to include only the intact capsule of the hip. This released any restraints due to the age related non-capsular stiffness or muscle contractures. There were ten ROM data sets for the intact specimens and four ROM data sets for the soft tissue released/intact capsule hip data sets. Each cadaver specimen started in the supine position, where BrainLAB reference arrays were affixed to the iliac crest of the pelvis and the lateral aspect of the femur for each hip. Soft tissue was removed around the anterior pelvic plane bony landmarks, medial and lateral femoral epicondyles and screws were inserted to accurately identify landmarks and eliminate variability errors when calculating ROM. An experience surgeon (RLT) evaluated hip ROM
with the same technique used intraoperatively during THA surgery. Combined hip motions of abduction/adduction, flexion/extension and external rotation/internal rotation were represented by three-dimensional (3D) data points. Ten data points were recorded per second using the BrainLAB VectorVision® 3.1 Hip Navigation software (BrainLAB AG, Germany) as the hip was manually moved throughout combinations of motion. The 3D data points were graphed in a point cloud format to depict all combinations of motion.

**Results:** Hip range of motion is a much more complex than previously reported. The hip capsule contains powerful and complex ligament structures creating restrictions in specific combinations of motion. Three-dimensional representation is required to understand the interrelationships between the motions. Motions found in these older specimens still had maximum motions that exceeded the motions reported in the literature. In certain extremes of motion, however, the capsule winding around the neck created forced substantial changes in the other two motions. The soft tissue released/intact capsule hips had roughly 10 degrees more motion in all directions compared to the intact cadaver hips. If this were indicative of the potentially greater range of motion available to younger patients, the ranges of motion reported in the literature would be substantially less than what was found. All four of the hips with only the soft tissue released/intact capsule had external rotation of 20-30 degrees in 40-50 degrees of extension. This combination of motion is greater than the motion obtained by almost all hip arthroplasty systems.

**Discussion:** Combinations of native hip range of motion should be recreated by a total hip arthroplasty. In order to replicate this motion, normal combined hip motions must be defined. This study is part of a series of studies attempting to define this standard. Without clearly defined normal combined motions, evaluation of the effects of implant geometry and surgical accuracy, with and without navigation, is not possible. We are presenting data on combined hip motions that has never been previously reported. In addition, we examined the effects of the hip capsule on motion. These normal hip motions create a standard that can be used to compare total hip arthroplasty components, report the effects of surgical implant placement variability, help determine the need for computer navigation and better evaluate and treat femoroacetabular impingement syndrome.
Total Hip Replacement

References


Does CT-Fluoro Matching Procedure Improve Registration Accuracy In Navigation THA?

TOKUNAGA K, WATANABE K, IMAI K, MURAOKA M

Niigata Hip Center, Kameda Daiichi Hospital, Niigata, Japan
ktokunagajp@yahoo.co.jp

Introduction: CT-based navigation THA is useful for Japanese patients suffering from hip osteoarthritis with femoral and pelvic deformities. Recently, CT-fluoro matching procedure has been developed for registration in navigation THA using VectorVision Hip (BrainLAB, Germany). In this system, the registration procedure is completed semi-automatically by matching the contours of fluoroscopic images to the contours of 3D bone model created in the computer. Because larger reference area is used for registration by this CT-fluoro matching procedure, the registration accuracy may be improved in comparison with the landmark matching procedure which previously used in VectorVision Hip. In addition, we do not have to expose bony surfaces to palpate for registration, the CT-fluoro matching procedure is prefer to minimally invasive surgery (MIS) in THA. The aim of this study is to evaluate the effects of the CT-fluoro and landmark matching procedures on the accuracy of implant position by measuring the cup and femoral stem angles in the post-operative CT images.

Materials and Methods: We analyzed the acetabular cup and femoral stem angles, and post-operative leg length discrepancies in consecutive 24 joints of 22 patients (group L) (19 females and 3 males, average of operative age was 64 years old) registered with the landmark matching procedure and 18 joints of 18 patients (group CF) (15 females and 3 males, average of operative age was 66 years old) registered with the CT-fluoro matching procedure. Lateral position was used in group L and supine position was used in group CF through MIS anterolateral (Röttinger’s modified Watson-Jones) approach. The acetabular cup and femoral stem angles in the post-operative CT images were measured using the VectorVision Hip planning software (BrainLAB). The cup angles was expressed as operative angle of Murray’s definition. The antetorsion of
the femoral stem was defined as the angle between the neck axis of the femoral stem and the functional femoral axis (the connecting line between the femoral head center and the center of the femoral epicondylar axis).

**Results:** The averages of the operative time were 144.3 ± 21.6 min in group L and 149.5 ± 41.3 min in group CF (p>0.05). The differences between the pre-operative plan and the post-operative measurement of cup inclination were 3.0 ± 2.4° in group L and 2.9 ± 3.1° in group CT, respectively (p>0.05). The differences between the intra- and post-operative measurement of cup inclination were 2.6 ± 2.2° in group L and 2.9 ± 2.4° in group CT, respectively (p>0.05). The differences between the pre-operative plan and the post-operative measurement of cup anteversion were 3.9 ± 4.4° in group L and 3.8 ± 2.0° in group CT, respectively (p>0.05). The differences between the intra- and post-operative measurement of cup anteversion were 4.7 ± 4.6° in group L and 3.2 ± 2.9° in group CT, respectively (p>0.05). The differences between the pre-operative plan and the post-operative measurement of femoral neck antetorsion were 5.4 ± 3.8° in group L and 5.5 ± 3.5° in group CT, respectively (p>0.05). The differences between the intra- and post-operative measurement of femoral neck antetorsion were 6.4 ± 4.9° in group L and 6.1 ± 3.7° in group CT, respectively (p>0.05). The averages of the postoperative leg length discrepancy were 1.7 ± 7.6 mm in group L and 1.9 ± 7.8 mm in group CF, respectively (p>0.05).

**Discussion:** The registration with CT-fluoro matching procedure is much easier than that with landmark matching procedure because we do not have to palpate over 60 points on the femoral and pelvic bony surfaces. In addition, the reference area with CT-fluoro matching procedure is much wider than that with landmark matching procedure, this new registration will provide better accuracy in registration. However, we could not detect any statistical differences in cup and femoral angles in this study. The reasons why CT-fluoro matching procedure did not improve the registration accuracy seemed to be two folds as follows: [1] we had a little experience of this new CT-fluoro matching procedure, and [2] the supine position was inconvenient for navigation THA combined with MIS antero-lateral procedure.
Accuracy Of New CT-based Fluoroscopy-matching Hip Navigation System

YANAGIMOTO S1, KANEKO H2, HUJITA Y1, FUNAYAMA A1, SUDA Y1, ENOMOTO H1, NIKI Y1, TOYAMA Y1

1 Dept. Of Orthop. Surg., Keio Univ., Tokyo, Japan
2 Dept. Of Orthop. Surg., Saitama National Hospital, Ohmiya, Japan

shigeruy55@gmail.com

Introduction: New technology of CT-based fluoroscopy-matching navigation system for THA (Total Hip Arthroplasty) was developed by BrainLAB Company in 2006. We started to use this system (Vector-vision 2.7.1.) first in the world from November 2006 and aimed to set the acetabular socket in optimal position and angle. By this system, the fluoroscopy-matching is completed easily before making surgical incision. So it has the advantage of no elongation in operative time. We evaluated the accuracy of socket setting angle in THA with this new system and compared the values with old CT-based land-mark matching THA system (Vector-vision 2.5.1).

Materials and Methods: Materials were 54 navigation THA cases. From November 2006, we have used new CT-based fluoroscopy-matching navigation system (Vector-vision 2.7.1., 3.5.) and taken post-operative CT scan to evaluate the accuracy of socket setting position in these cases. For 35 cases in these 54 cases, at the same time in THA, CT-based land-mark matching system (Vector-vision 2.5.1) was used together and compared the accuracy in both systems. For 35 cases with dual navigation usage, the procedure was followed. In both systems, same pre-operative segmentation and planning for each patient were used from pre-operative CT scan data. At first the reference frame (tracker) with infra-red makers was set on patient’s iliac crest. Then two different direction (at least more than 20 degrees different) fluoroscopic figures of pelvis were taken. Fluoroscopy-matching registration with these figures (Vector-vision 2.7.1, 3.5) was done before starting surgical incision. Old land-mark matching registration (Vector-vision 2.5.1) was done at the same time in the operative fields. Then we checked the accuracy of registration for these different two systems together.
during operation. Acetabular socket was set following these two systems. In these systems operative angle, which was referred from Murray, was used to show the setting angle of acetabular socket. The value of socket setting angle for each case was recorded. Post-operative CT scan evaluation was done for theses cases. We usually used 3D-tenplating system soft wear (Japan Medical Materials Co.) for CT evaluation and measured the inclination and anteversion angle of acetabular socket precisely. The values of final verification angle during operation in these different systems were compared with post-operative CT measurement value.

**Results:** Result 1. Over all results (54 cases with CT-based fluoroscopy matching system): Average setting angle (operative angle) of socket in these 54 cases were 41.3 +/- 4.6 degree (on standard deviation) in inclination angle, and 28.7 +/- 7.2 degree in anteversion angle. The absolute difference in 54 cases between final verification during navigation THA and post-operative CT evaluation was on average 2.6 +/- 2.3 degree in inclination angle, and 3.2 +/- 2.8 degree in anteversion angle. Result 2. Comparison between fluoroscopy-matching and land-mark matching systems (35 cases): The absolute differences in 35 cases between land-mark matching navigation(Vector-vision 2.5.1) and post-operative CT evaluation was on average 5.4 +/- 3.9 degree in inclination angle, and 4.9 +/- 4.3 degree in anteversion angle. On the other hand, the absolute difference in these 35 cases between fluoroscopy matching navigation and post-operative CT evaluation showed almost same accuracy compared with all over 54 cases. It showed on average 2.4 +/- 1.7 degree in inclination angle, and 3.6 +/- 2.9 degree in anteversion angle. In both comparison of inclination and anteversion angle, new fluoroscopy matching system showed higher accuracy. There was statistically difference (p<0.05) between these two systems in inclination angle.

**Discussion:** There are many kind of navigation systems for THA, for example, image-free navigation, fluoroscopy-navigation and CT-based navigation. From 2003, we have used CT-based navigation system for THA. For CT-based navigation, it needs pre-operative planning. So it takes additional time and sometimes is not simple. The reason to continue the usage of CT-based navigation system in our institute is the high accuracy of the system and possibility of advancement in the future. Until 2006, we have used CT-based land-mark matching navigation system. We reported the accuracy of land-mark matching before. The absolute differences in 148 cases in our institute between final verification angle during THA and post-operative CT evaluation were on average 4.2 degree in inclination angle, and 4.3 degree in anteversion angle.
angle. It needs the high technical skill to improve the accuracy of land-mark matching during THA. Careful and accurate touching on adequate points in operative-fields is need. New CT-based fluoroscopy matching system has many merit compared old land-mark matching system. The technique to use this new system is very simple, and it takes only about additional 20 minutes. Registration procedure using fluoroscopic figures has finished before making surgical incision. So it need no elongation time during THA surgery. From the result of this study, CT-based fluoroscopy matching system showed high accuracy. Differences between verification angle during surgery and post-operative CT measurement angle (2.6 degree in inclination angle, and 3.2 degree in anteverision angle) was apparently small compared with land-mark matching values. And the comparison between fluoroscopy matching and land-mark matching in 35 cases showed same result. The merits of new CT-based fluoroscopy matching navigation system are simplicity of using technique, no elongation of surgical time, and high accuracy even in severe deformity case. Conclusion: New technology of CT-based fluoroscopy-matching navigation hip system is very useful for accurate socket setting and no need of additional surgical time. This system is also useful especially for the patient with severe hip joint deformity.

References
Precise Estimation Of Post-operative Cup Alignment From Single Standard X-ray Radiograph

ZHENG G¹, ZHANG X¹, STEPPACHER SD², TANNAST M²

¹ MEM Research Center, ISTB, University of Bern, Switzerland
² Department Of Orthopaedic Surgery, Inselspital, University Of Bern, Switzerland

Guoyan.Zheng@MEMcenter.unibe.ch

Introduction: 2D anteroposterior (AP) pelvic radiographs, despite their inferior accuracy in comparison to 3D techniques based on CT data, are the standard imaging method for the evaluation of cup orientation following total hip arthroplasty (THA) [1], largely due to the simplicity, availability, and minimal expense associated with acquiring these images. While plain pelvic radiographs are easily obtained, their accurate interpretation is complicated by the wide variability in individual pelvic position relative to the X-ray plate. In THA, increased pelvic tilt would result in a significant decrease in apparent prosthetic cup anteversion and vice versa [2]. Thus, position variations in acquiring X-ray radiographs affect the accuracy of studies correlating cup position to instability, wear, and osteolysis.

Previous works: 2D-3D image registration methods [3] [4] have been introduced to estimate the rigid transformation between preoperative CT volume and postoperative radiograph(s) for an accurate estimation of the postoperative cup alignment relative to an anatomical reference, which is a plane called the anterior pelvic plane (APP) defined by the anterior superior iliac spines (ASIS) and pubic tubercles. However, these methods require either multiple radiographs [3] or a radiograph-specific calibration [4]. Furthermore, these methods were only evaluated on X-ray radiograph(s) without gonadal shielding, which may post a challenge for them.

Materials and Methods: In this work, we developed a program called „HipMatch”, where we proposed to use a hybrid 2D-3D registration scheme [5] combining a landmark-based 2D-3D matching with an intensity-based
2D-3D registration to find the rigid transformation between a preoperative CT volume and single standard X-ray radiograph. Our methods do not require a radiograph-specific calibration and can work with a X-ray radiograph with gonadal shielding. The only information that we assume to know about the radiograph is the image scale (pixel/mm) and the distance from the focal point to the imaging plane or to the film. As long as the radiograph is acquired in a standardized way, which is performed in a clinical routine [6], they can be estimated by performing one-time calibration.

Our landmark-based 2D-3D matching uses following anatomical landmarks: the left and right acetabular centers, the pubic symphysis, and the middle of the sacrococcygeal joint. These landmarks are interactively defined from both the X-ray radiograph and the CT volume to get their 2D positions in the X-ray image and their 3D positions in the CT volume, respectively.

Without the use of fiducial markers, the landmark-based 2D-3D matching can not fulfill the accuracy requirements of our application and is complemented by an intensity-based 2D-3D registration. The challenge here is the big area occlusion caused by gonadal shielding which creates large differences between the X-ray radiograph and the digitally reconstructed radiograph (DRR) obtained from the CT volume data by simulating X-ray projection given the current estimation of the rigid transformation, and contains very little useful information to aid registration. In this work, we solve this problem by combining a recently introduced spline-based multi-resolution 2D-3D registration scheme [7] with a similarity measure that is derived from Gibbs random field theory [8], which allows us to effectively incorporate spatial information into the intensity-based 2D-3D registration.

Results: We designed and conducted experiments on two clinical datasets and a cadaveric pelvis dataset. As there are no ground truths available for the two clinical datasets, we use them to qualitatively evaluated the effectiveness of the landmark-based 2D-3D matching and the accuracy of the hybrid 2D-3D registration scheme. Fig.1 shows one example. The input X-ray radiograph is shown in Fig.1(a). Fig. 1(b) shows the end of the landmark-based 2D-3D matching and the beginning of the intensity-based 2D-3D registration. The edges extracted from the DRR are superimposed onto the X-ray radiograph. An accurate matching between the X-ray radiograph and the DRR was observed. To quantitatively evaluate the measurement accuracy of the proposed approach, a cadaveric pelvis and an all polyethylene acetabular component (Charles F. Thackray, Leeds, UK) were used. Before the prosthesis was implanted, we did...
a CT scan of the cadaveric pelvis. After the prosthesis was implanted, we took 9 radiographs by putting the pelvis in different tilt and rotation positions relative to the X-ray plate. To get the ground truth about the prosthesis orientation relative to the pelvis, we did another CT scan after the prosthesis was implanted. Custom-made software was used to extract the ground truth from the second CT scan. Using these data, we performed two studies. In the first study, each one of the 9 radiograph was used together with the first CT scan to estimate the prosthesis orientation. In the second study, to simulate the occlusion caused by gonadal shielding, we intentionally set a region covering 1/5th - 1/3th of the valid image area of each radiograph to a constant gray value. We then used each one of these radiographs together with the first CT scan to estimate the prosthesis orientation. The differences between the radiographic measurements using the method introduced in [1] and the ground truth, and the differences between the estimated angles in both studies and the ground truth are presented in Table 1. Differences of 11.9° +/- 7.0° for anteversion and differences of 1.8° +/- 1.6° for inclination were found when the radiographic measurements were compared to the ground truth. With the help of the hybrid 2D-3D registration scheme, the differences were changed to 1.7° +/- 1.1° for anteversion and 1.0° +/- 0.6° for inclination, respectively, which proved the accuracy of the proposed approach. With the simulated gonadal shielding, the differences were slightly higher but still in the acceptable ranges [1]: 2.6° +/- 2.0° for anteversion and 1.1° +/- 0.7° for inclination.

![Fig. 1. (a) X-ray radiograph with gonadal shielding; (b) the beginning of the intensity-based 2D-3D registration; and (c) the end of the intensity-based 2D-3D registration](image)

**Table 1. Experimental results**

<table>
<thead>
<tr>
<th>Angle</th>
<th>mg_1</th>
<th>mg_2</th>
<th>mg_3</th>
<th>mg_4</th>
<th>mg_5</th>
<th>mg_6</th>
<th>mg_7</th>
<th>mg_8</th>
<th>mg_9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anteversion (°)</td>
<td>13.1</td>
<td>11.1</td>
<td>24.1</td>
<td>20.8</td>
<td>10.4</td>
<td>19.2</td>
<td>17.8</td>
<td>12.5</td>
<td>9.1</td>
</tr>
<tr>
<td>Inclination (°)</td>
<td>0.5</td>
<td>5.1</td>
<td>3.6</td>
<td>1.2</td>
<td>0.6</td>
<td>1.0</td>
<td>0.5</td>
<td>1.3</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Difference between the estimation results of the first study and the ground truth:

| Anteversion (°) | 2.4  | 0.4  | 0.4  | 0.1  | 0.9  | 0.9  | 2.5  | 2.2  | 1.8  |
| Inclination (°) | 1.4  | 0.2  | 1.6  | 0.9  | 1.0  | 2.0  | 0.1  | 1.8  | 0.5  |

Difference between the estimation results of the second study and the ground truth:

| Anteversion (°) | 5.9  | 0.2  | 0.3  | 5.3  | 1.4  | 1.8  | 3.6  | 2.1  | 3.2  |
| Inclination (°) | 1.6  | 0.1  | 1.8  | 1.0  | 1.0  | 2.1  | 0.2  | 1.2  | 0.7  |
Discussion: In this work, we successfully developed a program for precisely estimating the postoperative cup alignment. Our program is more appropriate for long-term retrospective study than those have been previously reported [3][4], which require either multiple radiographs [3] or a radiograph-specific calibration [4], both of which are not available for most retrospective studies. More clinical study results are expected by the time of CAOS symposium.

References
Application Of CT-based Navigation For Revision THA And THA For Hip With Metal Implants

Nakamura N1, Sugano N2, Nishi T2, Kakimoto A3, Iwana D3, Kitada M3, Yamamura M3

1 Center Of Arthroplasty, Kyowakai Hospital, Osaka, Japan
2 Department Of Orthopaedics, Osaka University Medical School, Osaka, Japan
3 Center Of Arthroplasty, Kyowakai Hospital, Osaka, Japan

nakamu@abox2.so-net.ne.jp

Introduction: The use of surgical navigation system in performing primary total hip arthroplasty (THA) has been proven to be beneficial especially for acetabular component positioning. Its use can reduce cup malpositioning, leading to minimize hip impingement, dislocation, wear and revision. Although good clinical accuracies of CT-based navigation system have been reported for primary THA, the accuracy and usefulness of its application for revision THA and THA for hip with metal implants such as screws and plates remains to be unknown. The purpose of this study is to evaluate the clinical accuracy of CT-based hip navigation system for revision THA and THA for hip with metal implants.

Materials and Methods: From December 2005, eleven consecutive patients who underwent revision THA or primary THA for hip with metal implants with the use of Stryker CT-based hip navigation system (Stryker-Leibinger, Freiburg, Germany) and Trident acetabular cup (Stryker) were included in this study. There were seven revision THA; three hips were revised due to recurrent dislocation and four were due to component migration. There were four post-traumatic arthritis with metal implants around the hip joint (three femoral neck fractures and one pelvic fracture). The average age of the patients was 68 years (35-83). For revision THA, preoperative AAOS classification of acetabular deficiencies were type I; 4 hips, type II; 2 hips, type III; 1 hip.
Preoperatively, CT scanning was performed and the data was transferred to preoperative planning workstation. We plan the position and the size of the acetabular cup three-dimensionally on the Stryker CT hip navigation software. Intraoperatively, after removal of metal implants, surface registration of the pelvis, acetabular reaming and cup placement were performed using CT-based hip navigation system according to the preoperative planning. Postoperatively, CT scanning was performed and alignment of the cup was assessed on the CT hip navigation software. The data was compared with the preoperative planning and intraoperative data.

Results: The average time for the intraoperative registration was 14 (2-36) minutes. The average RMS (root mean square) was 0.70 (0.42-1.07) mm, and the average 94% of registered points were used for surface matching. Postoperative CT measurement showed that average cup alignment was 42±2.7 (36-47) degrees inclination and 22±4.3 (12-29) degrees anteversion. The average differences between postoperative measurement and preoperative planning were 1.7±2.4 (0-7) degrees inclination and 3.2±1.9 (1-6) degrees anteversion. The average differences between postoperative and intraoperative measurement were 1.5±1.6 (0-5) degrees inclination and 1.9±1.0 (0-3) degrees anteversion.

Discussion: Revision THA and THA for failed open reduction and internal fixation around hip joint are thought to be technically demanding procedures. Complications such as dislocations and limb length inequality sometimes occur because of the anatomical deformities and soft tissue contractures. Importance of preoperative planning has been emphasized and use of navigation system, especially CT-based navigation system is thought to be advantageous. On the other hand, CT images of these patients have an issue of metal artifacts caused by the implants. In this study, we could achieve the cup alignment as accurate as those of previously reported in the primary THA. One of the reasons for this result is that, in Stryker CT-based hip navigation system, we don’t have to use the points in the acetabulum for registration. Instead, we could use extraarticular bone surface where the influence of metal artifacts was less and surface model creation was easier. In conclusion, this CT based navigation system was effective for revision THA and THA for hip with metal implants.
References


Navigation Versus Radiographic Measurements In The Open-wedge And Closed-wedge High Tibial Osteotomy Using Computer Assisted Surgery (CAS)

Bae DK, Song SJ, Noh JH, Chang WS, Jung KY

Department Of Orthopaedic Surgery, School Of Medicine, Kyung Hee University, Seoul, Korea
tesstore@empal.com

Introduction: To compare the measurements using a navigation system and radiographic measurement in an open or closed wedge high tibial osteotomy (owHTO or cwHTO) under navigation control. To identify the difference of postoperative mechanical axis measurements between the navigation system and radiograph according to the types of HTO and to identify the change of tibial posterior slope angle after HTO according to the types of HTO.

Materials and Methods: 32 owHTO and 51 cwHTO were performed using the navigation system for the medial compartment osteoarthritis of the knee, and they were prospectively analyzed. The postoperative mechanical axis % (MA%), which is planned on the navigation system, was 62%. The mechanical axis (MA) and MA% were measured on the navigation system. Puddu plate and miniplate staple were respectively used to fix the osteotomy site in owHTO and cwHTO.

The preoperative and postoperative, MA and MA% were measured on the radiographs. The angles measured on the navigation system and radiographs were compared (correlation analysis). The PO MA (Xray-Navi) is defined as the difference of postoperative MA measurements between the navigation system and radiograph, which is “the MA on the radiograph minus the MA on the navigation system”. The PSA (PO-Preop) is defined as the change of tibial posterior slope angle (PSA) after HTO, which is “the postoperative PSA
on the radiograph minus the preoperative PSA on the radiograph”. The PO MA(Xray-Navi) after owHTO and the PO MA(Xray-Navi) after cwHTO were compared(Student t test). The PSA(PO-Preop) after owHTO and the PSA(PO-Preop) after cwHTO were compared(Student t test). The postoperative complications were checked.

Results: In the owHTO under the navigation system, the mean MA before osteotomy was varus 8.8°. The mean MA and MA% after fixation were valgus 2.7° and 57.7%, respectively. On the radiographs, the mean MA was varus 9.5° preoperatively and valgus 4.0° postoperatively. The mean MA% was 9.5% preoperatively and valgus 64.7% postoperatively. There were positive correlations between the values measured with the navigation system and the radiographs(r>0.5, p<0.001). In the cwHTO under the navigation system, the mean MA before osteotomy was varus 8.3°. The mean MA and MA% after fixation were valgus 3.5° and 62.0%, respectively. On the radiographs, the mean MA was varus 7.6° preoperatively and valgus 1.6° postoperatively. The mean MA% was 16.0% preoperatively and valgus 56.7% postoperatively. There were positive correlations between the values measured with the navigation system and the radiographs(r>0.3, p<0.02). The mean PO MA(Xray-Navi) after owHTO was 1.3°and the mean PO MA(Xray-Navi) after cwHTO was -1.9°(p=0.000). The mean PSA(PO-Preop) after owHTO was 5.3°and the PSA(PO-Preop) after cwHTO was -1.9°(p=0.000). There were 4 cases of screw breakages after the owHTO using the Puddu plate.

Discussion: There were significant correlations between the values measured on the navigation system and radiographs in an open and closed wedge high tibial osteotomy using a navigation system. The correction angle from the navigation system is reliable, predictable and controllable during surgery. The measured values of the postoperative MA on the radiograph had a tendency to be larger than that on the navigation system after the owHTO and to be smaller after the cwHTO. The posterior tibial slope angle had a tendency to increase after the owHTO and to decrease after the cwHTO. These tendencies need to be considered.
Analysis Of The Effect Of The Laterally Elevated Wedged Insole And High Tibial Osteotomy To The Patient With Medial Compartment OA Of The Varus Knee Using 4d Gait Analysis System

KAWAKAMI H1, SUGANO N2, YONENOBU K3, YOSHIKAWA H1, HATTORI A4, SUZUKI N6

1 Department Of Orthopaedic Surgery, Osaka Police Hospital, Osaka, Japan
2 Department Of Orthopaedic Surgery, Osaka Univ. Graduate School Of Medicine, Osaka, Japan
3 Department Of Orthopaedic Surgery, Osaka-Minami Medical Center, Osaka, Japan
4 Institute For High Dimensional Medical Imaging, Jikei Univ. school Of Medicine, Tokyo, Japan

hkawakami-osk@umin.ac.jp

Introduction: A laterally elevated wedged insole and high tibial osteotomies are effective treatments for the patients with medial compartment osteoarthritis of the varus knee. The aim of these treatments is to reduce the load on the medial compartment of the knee. The biomechanics of these treatments, however, have not been clarified in a dynamic status. We developed the 4-dimensional motion analysis system for calculating the locus of the dynamic loading axis based on the Mikulicz line on the knee joint. The purpose of this study is to evaluate (1) the locus of the dynamic loading axis of the lower limb through the knee joint, (2) the axial alignment of the lower limb, and (3) the pain scale during walking with and without a laterally elevated wedged insole before high tibial osteotomy, and to compare then to those post-operatively.

Materials and Methods: The subject of this study was a patient with medial compartment OA of the varus knee. The patient was a 76-year-old female. OA stage of the varus knee according to the Kellgren and Lawrense criteria on plain radiographs was grade 2. The left knee of the patient treated by high tibial
osteotomy using hemicallotasis. For the gait analysis system, the bone structure of the lower limb and the relative position of skin markers were acquired from CT images. 3D skeletal models of the femur, tibia, and reflective markers were reconstructed with Analyze PC 3.0. Motion capture data was acquired from spherical skin markers with the VICON system (Oxford Metrics Ltd). The movement of the skeletal models during gait was calculated based on the movement of the markers. The locus of the dynamic loading axis on the knee joint was defined as the point on the proximal tibia joint surface that intersected with the dynamic loading axis of the lower limb during gait. The loading axis based on the Mikulicz line passed through the center of the femoral head and the centroid of multiple points of the distal tibia joint surface. The coordinate point of the locus (the passing point of the loading axis on the knee) was evaluated by calculating the ratio of the point on the proximal tibia joint surface to the medial compartment joint width in the lateral direction. The lateral movement of the loading axis between the heel contact and the loading response peak during gait was calculated. The axial alignment of the lower limb (hip-knee-ankle angle) at the loading response peak during gait was calculated. The laterally elevated wedged insole was made by ethylene vinyl acetate with elevations of 7mm inclined at 11 degrees. The insole was fixed to the bilateral soles of the patient with a supporter designed to fit around the ankle and foot joint. Using this system, the data of pre-operative walking, pre-operative walking with the laterally elevated wedged insole and post-operative walking after 6 months were acquired. The passing points of each dynamic loading axis on the knee were compared at the characteristic point in the stance phase of the gait.

**Results:** The knee pain during gait after the treatments was improved from 100/100 preoperatively to 20/100 with the laterally elevated wedged insole and to 0/100 6 months after high tibial osteotomy. The locus of the dynamic loading axis of pre-operative walking passed through the medial side of the proximal tibia joint surface. The locus of the dynamic loading axis of pre-operative walking with the laterally elevated wedged insole passed through the medial and posterior side of the proximal tibia joint surface. The locus of the dynamic loading axis of post-operative walking passed through the center of the proximal tibia joint surface and became more stable in the lateral direction than those before surgery. On the loading response peak, the passing point on the proximal tibia joint surface was 127% of medial joint width preoperatively without the insole, 115% with the insole, and 15% post-operatively. The axial alignment of the lower limb (hip-knee-ankle angle) at the loading response peak was -16 degrees pre-operatively, -15 degrees during pre-operative walking with the insole, and 3 degrees post-operatively. Lateral movement between the heel
contact and the loading response peak during gait was 44% of the medial joint width preoperatively without the insole, 39% pre-operatively with the insole, and 5% post-operatively.

**Discussion:** The laterally elevated wedged insole and high tibial osteotomy reduced the knee pain effectively for the patient with medial compartment osteoarthritis of the varus knee. Our data showed the changes of the locus of the dynamic loading axis during gait. The laterally elevated wedged insole did not change the axial alignment of the lower limb substantially when compared to high tibial osteotomy. High tibial osteotomy revealed realignment of the lower limb and made the dynamic axial alignment of the lower limb stable in the lateral direction. On the other hand, the laterally elevated wedged insole did not change the axial alignment of the lower limb or the lateral stability. Yasuda et al. found that, in a static standing position, the laterally wedged insole increased the valgus angle of the subtalar joint by radiological assessment. So the effect of the insole on pain relief may be reduction in the load of the medial compartment of the knee by the movement of the subtalar joint.

**References**

Impact In The Treatment Of Calcaneal Fractures By 3d-fluoroscopy

MAEGERLEIN S1, UNGER A2, QUEITSCH C1, JUERGENS C1, SCHULZ AP2

1 Dept Trauma & Orthopaedics, Bg Trauma Hospital Hamburg, Germany
2 Dept Trauma & Orthopaedics, University Hospital Luebeck, Germany

maegerlein@apschulz.de

Introduction: Subtalar incongruity over 1 mm can lead to early post traumatic arthritis of the subtalar joint. Conventional 2-D fluoroscopy does not enable assessment of small incongruitities intraoperatively. The use of intraoperative 3-D-fluoroscopy enables visualisation of bone structures three-dimensionally and thereby recognition and correction of any remaining incongruities.

Materials and Methods: Study design was prospective with consecutive patients in a predetermined time-scale that met the inclusion criteria. In the period from October 2002 until October 2004 we treated 58 patients with intraarticular calcaneal fractures with an internal fixator and intraoperative 3-D fluoroscopy. We saw 50 men an 8 women with an average age of 42.3 years (19 - 59 years). The most frequent cause of accident was a fall (n=48) from an average height of nearly 3 m. According to the classification of Essex-Lopresti predominantly joint depression types occured (n=54), in 4 cases tongue type fractures. After routine praeoperative CT diagnostics a classification according to Sanders took place: 18 fractures were type II, 33 fractures type III and 9 were classified type IV.

Surgical treatment of the fractures took place on average after an interval of 8,5 days (7 to 11). In all cases a 3-D-fluoroscopy was performed after reduction and temporary fixation of the fracture. All patients had prae- and postoperative x-rays, so the change of the Boehler’s angle and the length of the hindfoot could be measured exactly. Clinical follow-up examination was performed on average 17.8 months postoperative.

Patient positioning was lateral on an operating table with a radiolucent carbon part. An extended lateral approach was performed, whereby the incision begins behind the distal fibula and runs L-shaped directly at the transition to the sole. The individually reduced bone fragments were fixed temporarily with K-wires, which were inserted through the sole. Control of the Reduction with 3-D-
Fluoroscopy: Siremobil ISO C 3D (Siemens Medical Solutions -Germany), a standard C-arm fluoroscopy coupled with a motor control for orbital motion and a computer-system for 3-D-reconstruction enables intraoperative 3D fluoroscopy control (fig. 2). The motorised C-arm provides fluoroscopic images during a single motor-driven orbital sweep of 190°. A defined number of images (50 or 100) are acquired at fixed angular increments. The system simultaneously produces a high-resolution, isotropic data volume from the individual images. Data can be processed by the surgeon intra-operatively, providing a multi-planar 2D reconstruction similar to the type provided with CT. On the reconstructions, the surgeon can visualise any remaining incongruence within the joint. Any remaining subtalar incongruity over 1 mm can be seen and immediately improved. Subsequently an internal titanium-fixator is modelled to the calcaneus and fixed with appropriate locked screws (fig. 3). Particular care is taken to fix the central fragment (posterior subtalar fragment) in a good and stable position.

Implant: As implant we used a multi-directional internal plate fixator (Tifix©, manufactured by LITOS, Hamburg/Germany) in all cases.

Results: The median theatre time was 72 minutes (53-112 minutes) including 3-D-fluoroscopy. In 22 cases (38%) a remaining incongruity of more than 1 mm was observed with the intraoperative 3-D-fluoroscopy. In all these cases reduction was repeated. The Boehler’s angle could be raised on average by 18 degrees (11° to 22°). The shortening of the hindfoot was on average improved by 13 picture millimetres (9 to 17 mm). In 4 cases another 3D fluoroscopy was performed after locked plate osteosynthesis. In one case two screws required repositioning. A secondary loss of correction was not seen. The achieved reduction could be fixed by the implant until full weight bearing was reached (table 1) in all cases.

<table>
<thead>
<tr>
<th></th>
<th>before</th>
<th>after operation</th>
<th>improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boehler’s angle(°)</td>
<td>0 (-10 to 5)</td>
<td>18 (15-38)</td>
<td>18</td>
</tr>
<tr>
<td>Hindfoot length( mm )</td>
<td>22 (18-31)</td>
<td>35 (30-41)</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 1. Results after surgical treatment

Complications experienced included 4 superficial wound edge necroses, which all healed completely with conservative management. One haematoma had to be revised and subsequently healed without any further problems. One case
developed a deep infection 20 days postoperatively. In this case the implant had to be promptly removed. Until follow-up, in no case an arthrodesis was required. At follow up examination all patients had returned to work, or had been judged fit to work by their GP. Three patients had to change their position. 25 patients were completely pain free at follow-up. One patient complained about constant pain. This patient had developed an early subtalar arthrosis after wound infection and early implant removal (table 2).

<table>
<thead>
<tr>
<th>Pain at Follow-up</th>
<th>No pain</th>
<th>Occasional/ mild pain, after heavy work/ sporting activities</th>
<th>Severe pain, after moderate work/ sporting activities</th>
<th>Constant pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>25</td>
<td>27</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: Pain at follow-up examination.

**Discussion:** The surgical treatment of displaced calcaneal fractures is a nowadays established standard. An accurate anatomical reconstruction of the subtalar joint with restoration of height, length and width of the calcaneus is necessary. Important for the biomechanics of the foot is the restoration of the tension of the plantar fascia by reconstruction of Böhlers angle and hindfoot length.

CT diagnostic enables us to an improved understanding of calcaneal fractures and led to a clinically relevant classification of these injuries. Surgical treatment of calcaneal fractures using 3-D fluoroscopy intra-operatively provides the opportunity to recognize and correct remaining subtalar incongruity. Using 3D imaging improves the quality and safety of surgical treatment of calcaneal fractures and reduces the risk of repeat surgery. The combination of 3D fluoroscopy with locked internal fixation could show promising results. Short term outcome shows a good functional result with a high percentage of patients returning to their previous occupation. If the rate of patients developing subtalar arthrosis will decrease by this management will have to be shown in long term follow up.
Autonomous Robotic Drill-assistance
For Femoral Intramedullary Nailing

OSZWALD M1, WESTPHAL R2, CITAK M1, KENDOFF D1, HÜFNER T1, WAHL FM2, KRETTEK C1, GOSLING T1

1 Department Of Trauma Surgery, Hannover Medical School, Hannover, Germany
2 Institute For Robotics And Process Control, Technical University Of Braunschweig, Braunschweig, Germany

Introduction: In intramedullary nailing, two types of free-hand drilling have to be performed by the surgeon: the proximal opening of the medullary cavity and the placement of the distal locking-bolts. Conventionally these drillings are being accomplished under usage of fluoroscopic imaging. Deviation of the ideal point of entry may lead to complications like malalignment of the extremity or even an iatrogenic fracture. Misplacement of the distal locking bolts may result in instability of the osteosynthetic system and/or mechanical impairment of the implants. Especially untrained surgeons cause increased irradiation to achieve an accurate drilling result. Additional damage to the bone or to soft-tissue as a result of repeated misplaced drillings is not to be disregarded. To conduct and to steady a drill represents another source of uncertainty. We hypothesize that a drill-guide conducted by a robot leads to an increased precision of drilling in comparison to the free-hand technique.

Materials and Methods: Specially designed drill-guides where mounted to the arm of an industrial robot. Two test-series were accomplished. In the first series, the proximal opening of the intramedullary cavity of the femur were examined. Seven cadaveric human femora were used. Two orthogonal fluoroscopic images of the proximal femur were aquired. Image processing was performed with a specially programmed software (hough transformation) to prepare an enhanced automatic contour-recognition. The bone axes were also recognized automatically and a virtual 3D reconstruction was established. The drilling trajectory was computed along the extension of the bone-axis. The robot then
moved the drill-guide on the trajectory with its tip to the point of entry. Now the drilling was performed by the surgeon.

In the second series, the drillings for the placements of the distal locking bolts were evaluated. We developed a special device to rigidly place a generic block (Synbone, Malans, Switzerland). The intramedullary nail could be inserted into the block in a standardized way. A metric scale allowed later measurements of the drillings. A digital camera could be mounted on metal bars on both sides of the device to capture standardized images of each side of the block. Two orthogonal fluoroscopic images, where obtained. They had to be acquired in a way, that the distal locking holes were centered and round. The number of actually necessary images to achieve this was recorded. The axis was recognized automatically by using the differences in contrast between the matrix of generic bone and the implant (intramedullary nail). Also the distal locking holes were recognized. The trajectories were computed. Again the robot automatically moved with the drill-guide on the trajectory. Now the surgeon could perform the drilling. We performed 40 robot assisted drillings in the generic blocks. As a control group, the drillings were also performed manually. The number of acquired fluoroscopic images was recorded. The pictures of the digital camera where evaluated with another software. Here the real trajectories could be computed and the accuracy of drilling was evaluated by calculating the deviation from the ideal orthogonal trajectory through the distal locking hole.

**Results:** 100% (n=7) of the intramedullary cavities of the proximal femur could be accessed successfully. The implantation of the intramedullary nail could be accomplished easily without any resistance.
In the second series, analysis of the digital images revealed a mean deviation of 0.94mm and 2.7° of the ideal trajectory using robotic assistance. Here in 100% of the cases (n=40), the distal locking hole was hit. Here in mean of 8.8 images was acquired. After manual drilling, 92.5% of the distal locking holes were hit. A mean deviation of 3.66mm and 10.36° was measured. A mean of 23.4 fluoroscopic images were needed. The differences between the two methods were statistically significant.

**Discussion:** Robotic drill assistance increases precision while reducing irradiation. Yet, the establishment as a stand-alone application has to be considered critically. Based on economical and logistical considerations, the application probably will only be accepted when a concomitant application for fracture reduction is available.
3d Navigated Placement Of Screws In The Sustentaculum Tali As A Treatment Of Intraarticular Calcaneal Fractures

RUEBBERDT A, HOFBAUER VR, RASCHKE MJ

Department Of Trauma-, Hand- & Reconstructive Surgery, University Clinic Of Muenster, Muenster, Germany

dr.ruebberdt@gmx.de

Introduction: There is consensus about the clinical relevance of intraoperative 3D imaging in osteosynthesis of intraarticular calcaneal fractures. Due to the complex anatomy of the calcaneus conventional 2D imaging doesn’t give the required information for secure and precise placement of screws for osteosynthesis. It is hypothesized that the misplacement of screws, especially of sustentacular screws which are close to the joint, can be reduced with the help of navigation. In the following study a new method for 3D navigated placement of sustentacular screws for treatment of intraarticular calcaneal fractures is presented and evaluated.

Materials and Methods: In a prospective, not randomized clinical trial 11 consecutive patients with 15 intraarticular calcaneal fractures were treated. The procedures were done one surgeon using intraoperative 3D navigation. Average age was 42.7 (24-66) years. In 9 cases the left calcaneus was fractured. There was no open fracture. Fracture classification was performed on the basis of CT scans according to SANDERS: n=2 IIA, n=5 IIB, n=4 IIC, n=2 IIIAC, n=2 IIIIC. A second generation C-Arm system [Orbic Arcadis 3D, Siemens, Germany] with integrated navigation [Navi Vision BrainLAB, Germany] was used. The navigation system tracks passive reference markers with IR cameras in real time. The accuracy of tracking is approximately +/- 1mm. In 12 patients osteosynthesis was done through an extended lateral approach. The reference base was placed longitudinally in the posterior part of the calcaneus. In three cases (n= 2 IIA, n = 1 IIB) osteosynthesis was achieved through a minimally invasive, percutaneous lateral approach following a reposition (WESTHUES - maneuver). A 1.2 mm K-wire was placed with a navigated drill guide. The
position was verified using 2D fluoroscopy and then the planned trajectory was drilled with a cannulated 2 mm drill and a referenced drilling machine. The length of the 3.5 mm screw was measured along the virtual trajectory of the navigated drill. For verification and documentation of the placed screws a second 3D scan was performed.

**Results:** In total 18 screws were placed in the sustentaculum tali using the new 3D navigation method (n=4 in minimally invasive technique). In spite of the small diameter of the K-wires no deviation was seen comparing the planned trajectory on the screenshots with the actual position of the screws in the post operative 3D scan. No loosening of the reference markers occurred during the navigation procedure. None of the navigated screws was misplaced (articular lesion / para-sustentacular position). Extra OR time due to navigation (DRB mounting, IR-camera and monitor adjustment, image acquisition, calibration) was in average 11.9 minutes (+/- 1.7 min, min. 9 min, max. 15.25 min).

**Discussion:** This first experience shows that the combination of intraoperative 3D imaging and navigation for implantation of sustentacular screws as a treatment of intraarticular calcaneal fractures is feasible with precise and reliable results. In Type IIC, IIIAC and IIIIBC fractures a secure osteosynthesis of the posterior articular joint and the commonly non-dislocated medial sustentacular fragment (reference fragment) is possible. Especially in minimally invasive treatment a high quality of osteosynthesis can be achieved using this new method.
Ergonomic Evaluation Methods On Computer Aided Surgery - Preliminary Design

Anselmi L1, Canina M1, Cerveri P2, Lopomo N3, Marcacci M4

1 Dipartimento Indaco - Product Usability Lab, Politecnico Di Milano, Milano, Italy
2 Dipartimento Di Bioingegneria, Politecnico Di Milano, Milano, Italy
3 Laboratorio Di Biomeccanica, Istituti Ortopedici Rizzoli, Bologna, Italy
4 Dipartimento Di Scienze Anatomiche Umane E Fisiopatologia Dell’apparato Locomotore, Università Di Bologna, Bologna, Italy

n.lopomo@biomec.ior.it

Introduction: The Computer Aided Surgery (CAS) methodology applied to Minimally Invasive Surgery (MIS), has led to the development of specific navigation systems that have showed a huge number of practical advantages for the physician and the patient; formally a more precise localization/orientation of implants (available information in pre-operative planning), more precision in surgical gestures, high reliability and repeatability of the surgical procedure (procedure standardisation), an accurate execution of complex tasks, an amplified surgeon dexterity. Nevertheless some disadvantages have emerged from the use of these systems themselves, in particular an additional time to surgical procedure (settings and easiness of use) and additional costs. The main problem is that the model used in CAS has been developed according primarily with technological innovation and not with surgeon demands, who indeed has to „adapt“ himself to the system. This aspect can have an influence also on the system performances and on the final surgical outcome.

The ergonomic approach requires a real knowledge of the characteristics and needs of the users and leads to the definition of the device requirements, depending on the real use the system is meant for and the context where the interaction man-machine happens. The ergonomic oriented design, based on the User Centred Design (UCD) principles, can be seen as guarantee for a real usability (effectiveness, efficiency, satisfaction) of surgical navigation systems.
Objectives: The main goal of this study is the definition of an integrated methodology that, through a precise characterization of single user needs, has to led to an ergonomic optimization of actual CAS system, structuring the technology around the surgeon himself. This research approach, including typical instrument of ergonomics, will allow a mapping of the main criticalities in the surgeon-system interaction, of the unease physical and cognitive conditions, of the resulting risk factors and of the user needs and expectations. This map, therefore, will allow the development of guidelines for designing and/or spotting innovative technologies able to satisfy the requirements detectable through the direct involvement of the surgeon, medical staff and environment analysis.

Materials and Methods: The project involves the use of adequate methods and instruments specific of human factors analysis; these methodologies allow a deep examination of implicit and explicit needs of the surgeon, by making a structured observation in the realm of operating room. The workflow will involve the development and integration of different phases, referring primarily to these aspects:

- survey and test for usability evaluation
- analysis of the psycho-physical interaction surgeon-CAS system
- evaluation of the critical aspects, referring to the technologies involved in navigation systems

The following ergonomic parameters will be used as reading keys for the analysis of:

- the posture: the surgical procedures are often the cause of dynamic and static postural stress that can lead to tiredness
- the manipulation: the standards for surgical instruments rapidly evolve in standardized design.
- the visualization: correct exposure, quality and intensity of the light that grants a direct vision
- the physical and mental workload: new technologies in the working field cause an augment of the psychological stress on the surgeon with a consequent increase of mental workload
- the context, i.e. the operating room: pre-existing environments adapted to the introduction of new technologies can weigh in a negative way on the mobility and efficiency of the surgeon and his staff.

The optimization of the system will be based on the maximisation of the
conditions and efficiency of the users work and the minimisation of the risks (both on the surgeon and on the patient side) and conditions that can lead to errors (Fig. 1).

In particular, in the repeated observation of the real surgery and the real use of CAS systems, the aspects to take into consideration are:

- psycho-physical capabilities of the final user (surgeon)
- memorization and cognitive processes involved in the surgical method
- training of the atypical clinical conditions
- expectations and stereotypes that could help the use of a traditional surgery system or a computer aided one.

Figure 1. Example of Surgeon Centred Design

**Results:** This project will define the main guidelines for optimizing the development of CAS systems, the system performance and reducing any possible clinical risk towards patient’s benefit. In details the use of ergonomic instruments can lead to:

- identify the critical aspects and the main components of the surgical process
- comprehend the limits in the development of the clinical instrumentations
- analyse and minimize the level of accidents or long run uneasiness.
- reduce the number of errors and the performance problems of the surgeon/instruments/patient system due to an overload of stress and tiredness

Therefore some specific expected results from this project are:
- implementation of the specific instruments used for computer-assisted surgery, which could reduce the invasiveness for the patient and could be, at the same time, easy-to-use and convenience for the surgeon
- optimization of the global working environment
- creation of new interfaces surgeon-system, adaptable in according with clinical needs.

References

Cooperative Robotic Assistant Surgery System

CASTILLO-CRUces RA, WAHRBURG J

Center for Sensor Systems, ZESS, University of Siegen, Germany

wahrburg@zess.uni-siegen.de

Introduction: The modular interactive computer-assisted surgery (modiCAS) project, settled in the Center for Sensor System (ZESS) at the University of Siegen in Germany, strives to develop an integral solution to different surgical problems by the combination of a navigation system and a robot arm with hands-on capabilities [3]. The system covers all stages of surgical procedures, going from preoperative planning, through intra-operative registration up to robotic assisted surgical intervention. Furthermore, the robotic system should provide assistance to the surgeon rather than substituting him/her. Assistance intends to improve the performance of the surgeon instead of delimitate or obstruct it. In other words, the surgeon must keep control of the surgical operation all the time while the robotic system simply becomes a tool at his/her disposition, which usage should be as intuitive as possible. Nevertheless, the absence of human mistakes cannot be completely assured. Therefore, surgeon freedom must be limited in a way that forbidden regions become unattainable so that accidental injuries can be prevented. For these reasons, a seamless and secure integration of the system within the operating room is consider a paramount issue for a successful assistance and represents an important requirement within the modiCAS project.

Materials and Methods: The robotic system is equipped with a force-torque sensor at its end-effector which provides a haptic interface for cooperative tasks. The surgeon is then able to freely guide the robot's end-effector with his/her own hands inside some predefined constrained area assuring that any movement toward a forbidden region becomes unreachable. Therefore, the concept of virtual fixtures proposed by Bettini et al. [1] is applied to the haptic interface. Any movement commanded by the surgeon is virtually constrained along permitted directions. These virtual fixtures are previously defined in the preoperative stage of the surgical intervention. Furthermore the system
compliance against forces applied by the surgeon can vary depending on the proximity to the patient. This integrates the robot seamlessly in the operating procedure, because there is no need to use other input-devices like mouse, touch screen or keyboard to directly control the robot.

The Virtual Fixtures (VF) are basically the separation of the 3D working space into two complementary subspaces, one containing all the preferred directions, and the other containing the non-preferred ones. Each preferred virtual direction is specified by a single virtual unit vector. Translation and rotation are treated with two separated subsets of unit vectors, \( S^T \) and \( S^\alpha \) respectively. In the case of translation, \( S^T \) specifies the directions along which the tool tip can move, whereas for rotation, \( S^\alpha \) specifies the axes of rotation about which the tool can rotate. These vectors are specified with respect to a target frame, which can be directly related to the patient by means of the navigation system. A VF can be composed of multiple directions, the combination of which permits different kinds of isotropic movements, which may be one dimensional (lines), two dimensional (planes) or even constrained three dimensions (tubes, cones, etc.). More complex paths can be achieved with a variable reference target frame. Parametric functions can be used to this propose.

The control strategy for the cooperative mode basically consists of two control loops: an inner velocity control loop at the joint level, and an outer admittance controller that modulates the end-effectors linear and angular velocities as a function of the applied forces. The admittance controller makes use of projection operators to project the applied forces into the two subspaces. A proper independent conditioning of these two subspaces makes possible to virtual constraint the working space in which the tool can be freely moved.

![Admittance controller for cooperative tasks during surgical interventions.](image)
Results: The first clinical application of the robotic assistance system has been carried out in total hip replacement surgery [2]. After successfully registration of the patient, the robot arm is able to keep a predefined position and orientation in relation to the patient where the surgeon is to operate. During such procedure it may be required the surgeon to temporarily interrupt the surgical procedure, moving the tool out of the working space maybe to have a closer look of the patient or to change tool. This can be done in a cooperative safety manner: an escape movement on the operating negative normal direction is applied in order to get out of the critical area nearby the patient in a safety way. After certain distance, the virtual constraint is shifted to an inverted conic form giving the possibility to locate the robot out of the way not to obstruct any other activity of the surgeon. On the same way, once the robot is pulled back to the working area, the virtual constraints procure that the original operating position and orientation are safely attained again so that the intervention can proceed. In this case no autonomous movement of the robot is required at all.

Discussion: Proving cooperative capabilities to the robot arm increases the level of integration of the assistant system in surgical interventions. The interaction between surgeon and robot becomes more intuitive and easier because the surgeon can directly guide the robot arm. Moreover, the concept of virtual fixtures is applied to improve the safety of the system during such cooperative modality. The surgeon maintains full control over the operation procedure while the system hinders the tool to enter in predefined forbidden regions.

References

CITAK M1, KENDOFF D2, O’LOUGHLIN P2, BRETN P1, KRIETEK M1, HÜFNER T1

1 Trauma Department, Hannover Medical School
2 Orthopaedic Department, Hospital For Special Surgery, New York

citak.musa@mh-hannover.de

Introduction: Computer assisted surgery in orthopedic and traumatologic surgery has been shown to increase accuracy and decrease x-ray exposure for both patient and surgeon. The accuracy depends on factors such as the hardware and software utilized as well as the skill and experience of the surgeon. A common problem encountered has been the effective coupling of new navigation techniques with pre-existing hardware. For example, the use of instruments with a diameter less than 2.5mm has proven to be troublesome with poor visualization on the navigation system as well as problems with bending of the instrument. However, with electromagnetic navigation systems, this issue is addressed by virtue of the fact that the instruments have inductors themselves thereby aiding detection during navigation. To date, these navigation systems are very commonly employed in orthopedic surgery. Furthermore, these single-use instruments are very expensive. The aim of this study was to develop and evaluate a method for navigation with instruments with a minimum diameter of 0.8 mm. As a clinical scenario necessitating such fine instruments, we have chosen a spinal injection procedure commonly used for chronic spine-related pain.

Materials and Methods: We developed an infiltration gun which could be connected to a 10 ml syringe. By pulling the trigger of the gun, a specific amount of medication can be injected into the human body. The gun has a reference base on top so that it can be calibrated with the navigation system (VectorVision, Brainlab, Feldkirchen, Germany). Furthermore, we developed a guiding rail which is fixed at the operation table. Using this guiding rail the direction of the gun can be defined. After fixing the gun, only parallel modifications of the trajectory are readily possible. We designed a conical needle which has
a proximal diameter of 2.5 mm and a distal diameter of 0.8 mm. In our pilot study to evaluate accuracy, we produced a plexiglass cube (10 x 10 x 10 cm) and attached a navigated reference base to it. In experiment A, we filled the cuboid with a ballistic gel made of gelatine. In experiment B, we filled it with pork meat and skin to simulate muscle, skin and tendon. As a target we placed a piece of metal (1 x 1 mm) into the middle of the cube. We acquired imaging data with the Iso C 3D (Siemens, Erlangen, Germany). We used a common 0.8 mm needle and the new conical needle. Both needles were first navigated free hand and secondly with the aid of the guiding rail. All experiments were repeated 10 times and repeated by three observers. The infiltration gun was filled with equal parts methylene blue and a contrast medium. Calibration was then performed. Following aiming of the target with the aid of the navigation system 1ml of the mixture of methylene blue and the contrast medium were injected. Following this another Iso C 3D control scan was performed. CT measurement software (Siemens, Erlangen, Germany) was used to measure the distance between the metal target and the injected solution in all cases.

**Results:**

**Experiment A (Tissue simulation)**
Free hand navigation with the conical needle had the highest degree of variation in terms of distance from the target. The average was 33.4 mm (range 3 mm to 66 mm). The highest accuracy was with the conical needle was achieved with the aid of the guiding rail. The average distance from the target was 0.53 mm (range 0 mm to 1.8 mm). The experiments with the common needle of 0.8 mm diameter and the guiding rail showed an average distance from the target of 0.7 mm (range 0 mm to 2.1 mm).

**Experiment B (Skin, muscle and tendon simulation)**
Free hand navigation resulted in an average distance from the target of 40.1 mm (range 12 mm to 75 mm). Whereas, use of the common 0.8 mm needle with the guiding rail resulted in an average distance from the target of 0.29 mm (range 0 mm to 1.3 mm). The conical needle achieved an accuracy of 1.01 mm (range 0 mm to 3.8 mm).

**Discussion:** Our experiments have demonstrated that precise navigation of fine instruments with a diameter less than 1mm is possible. While mechanical bending of the instruments remains problematic, free hand navigation is a major factor in this. However with the aid of the guiding rail it was possible to define the direction more accurately. The guiding rail was able to minimize bending of the instruments. The conical needle did not show any advantage
in terms of minimizing bending. In the future, it may be most efficient to use guiding rails or robotic assistance to navigate fine instruments. Furthermore, it is conceivable that ‘intelligent’ instruments may be developed that could detect user error or an incorrect trajectory and alert the user or correct the direction of instrument.
Technical Evaluation Of The Positional Accuracy Of Computer Assisted Surgical Systems

Clarke JV¹, Deakin AH¹, Picard F¹, Nicol AC²

¹ Department Of Orthopaedics, Golden Jubilee National Hospital, Clydebank, Glasgow, Scotland
² Bioengineering Unit, University Of Strathclyde, Glasgow, Scotland

jvclarke@doctors.org.uk

Introduction: The role of CAOS systems is now well established in several areas of orthopaedic surgery and their popularity world-wide continues to grow. The increasing use of these systems, particularly in knee arthroplasty, has been supported by several prospective, randomised clinical trials that demonstrate a more accurate final position of implanted devices compared with conventional instrumentation techniques [1-4]. CAOS technology is constantly evolving along with its expanding list of potential indications. This requires the adaptation of both software and hardware components. It is essential therefore that potential users have confidence in the claimed accuracy of these systems. Currently the only technical information available is that provided by the manufacturers. The aim of this project therefore was to design and manufacture a standardised measurement object (phantom) to allow independent evaluation of CAOS system performance and evaluate a novel, portable, non-invasive system.

Materials and Methods: The American Society for Testing and Materials (ASTM) International along with CAOS International recently drafted a standard for measuring technical accuracy of navigation systems [5]. This proposed standard was obtained and its recommendations used to design a phantom model (shown in figure 1). This consisted of a 150x150x20mm base plate and two additional levels including a single 30° slope. This created a 3D surface on which points could be placed. Co-ordinates for 21 points were given to establish the x, y and z axes of a Cartesian system and then to have points at a variety of known locations in this 3D space. The final model was machined from a billet of marine grade aluminium alloy 6082-T6 (which was chosen for its dimensional stability) using a vertical computer numerical controlled (CNC)
milling machine with the co-ordinate points drilled with a Ø0.8mm 60º BSO centre drill to a depth of 1.2mm. The drill holes, with chamfers of Ø1.0mm, were designed to accommodate a ball-nosed pointer tip of a known diameter which remains at the same position in space at all orientations of the pointer. A Perspex base unit with three different sites of rigid tracker attachment was made to hold the phantom and provide its reference base. This avoided the need to directly modify the phantom itself which could have resulted in the potential loss of structural accuracy. It also allows different metal pins (secured in position by grub screws) and corresponding trackers to be attached permitting the evaluation of many different systems.

**Results:** The final design has since been used to measure positional accuracy of a novel portable navigation system and demonstrate that it is not yet suitable for clinical evaluation due to errors of 1 - 6 mm in point location. As well as its role in the development of a new system, it has also allowed independent technical validation of current pre-existing navigation systems in use in our department. This has supported the performance claimed by the manufacturers with three-dimensional errors in single point location of less than 1mm. Inter- and intra-observer variability is very low and demonstrates a high level of repeatability when evaluating these CAOS systems with our phantom model.

**References**
Evaluation Of The Efficiency Of The Zero-dose C-arm Navigation Approach

DE LA FUENTE M1, BELEI P1, MÜLLER M2, MUMME T3, RADERMACHER K1

1 Chair Of Medical Engineering, Helmholtz-Institute For Biomedical Engineering, RWTH Aachen University, Aachen, Germany
2 Department Of Orthopaedic And Trauma Surgery, University Hospital Bonn, Bonn, Germany
3 Department For Orthopaedics, Aachen University Clinic, RWTH Aachen University, Aachen, Germany

fuente@hia.rwth-aachen.de

Introduction: The efficiency and success of computer assisted fluoroscopic navigation systems mainly depends on the quality of the image acquisition process. The quality is mainly affected by three factors: (1) obtaining the desired view of specific anatomical structures, (2) the relative orientation of multi-planar x-ray images and (3) the applied amount of radiation dose to the patient as well as to the OR staff. The high radiation dose depends on the relative huge amount of unusable images that can not be reasonable used for navigation. Many times, the c-arm is even reoriented using continuous radiation to get the desired image.

Theoretical analyses showed that in addition to the optimal field of view of the image, the relative orientation of multi-planar x-ray images has a considerable influence of the expected navigation accuracy. The question arises, whether the anyway available computer assisted systems can be used (besides the navigated surgery) to navigate the c-arm before image acquisition to get x-ray images with maximized accuracy and minimal radiation exposure.

Materials and Methods: For lower extremities a system called Zero-Dose has been developed, which is able to generate a real-time preview of the expected x-ray image without using radiation. Based on position data from an optical tracking system a deformable bone-model is adapted by a percutaneously palpation of three landmarks of the individual anatomy. In order to take into account the thickness of the overlaying tissue, an position offset was added.
To evaluate the efficiency and accuracy of the approach, a cadaver study was performed on 6 full body human specimens (left and right side) comparing the Zero-dose approach to a conventional, not-navigated repositioning of the c-arm. The task of 8 different users (surgeons and engineers) was to acquire in each case two perpendicular x-ray images of the hip joint, of the knee joint and of the femoral diaphysis.

**Results:** The analysis of the acquired data revealed that the number of required x-ray images could be reduced to 7 (mean) (min 6, max 11) using the Zero-dose system, meanwhile the conventional comparison group required a mean amount of 11 x-ray images (min 7, max 20). The mean time of both groups did not differ significantly (Zero-dose: 5:50 min.; conventional: 6:00 min). Concerning the image quality, in the conventional group a big variation of the relative orientation of the images was measurable, whereas using the Zero-dose system quasi-orthogonality of the images could be reached.

**Discussion:** The cadaver study showed that using the Zero-dose system the amount of x-ray images could be significantly reduced. It is remarkable that the amount of required x-ray images was up to 20 images in the conventional group. The reason may be the huge body weight of the specimens, where it was difficult to forecast the target positions. It was also interesting to notice that the time need in the Zero-dose group was similar to the conventional group. Even the maximal time was reached in the Zero-dose group with 11 minutes.
Having the real-time visualization of the expected x-ray image, the users tried to optimize the view and did not pay attention to the time. Meanwhile, the system has been adapted to include also x-ray opaque parts of the OR-table that may occlude important anatomical structures. Current modifications to use the system for spine applications are promising.

Acknowledgement:
This work has been funded in part by the German Ministry for Education and Research (BMBF) in the framework of the OrthoMIT project under grant No. BMBF 01EQ0402 / BMBF 01IBE02C. The authors would also like to thank the Institute of Anatomy of University of Bonn for the provision of the specimen.
Accuracy Of Center Of Femoral Head And Talocrural Joint Calculated By Navigation System

ENOMOTO H, MATSUZAKI K, MATSUMOTO H, OTANI T, NIKI Y, SUVA Y

Department Of Orthopaedic Surgery, Keio University, Tokyo, Japan

hiro-eno@joy.ocn.ne.jp

Introduction: The advantages utilizing navigation system in TKA have been demonstrated previously especially in terms of coronal alignment. Although surgeon’s side errors such as misplacement of cutting block or incorrect cutting by bone saw according to the guide were pointed out as factors influencing the accuracy of navigation surgery, the errors of navigation system itself have not been elucidated so far. To acquire the fidelity to recreate the mechanical axis according to a planning in TKA with navigation, the adequate registration of hip and ankle joint center is essential. The purpose of this study is to clarify the discrepancy between the centers calculated by navigation system and those in real.

Materials and Methods: Navigation TKA (Genesis II; Smith & Nephew) was performed with Virtual Fluoroscopy-based Navigation System Stealth Station iON (Medtoronic) on 11 knees with OA and 5 knees with RA. Reference frames were set on femur and tibia. On this system the center of femoral head is calculated automatically by a passive motion of a hip joint while an assistant surgeon hold pelvis not to move. Ankle center is registered automatically as well at 40 : 60 between apexes of medial and lateral malleolus. The images of AP view of hip, knee, and ankle are taken and captured into PC with the calibration target. The data used during surgery were installed in PC and analyzed using Turbo Sketch Ver.8 (IMSI) later. The accuracy of hip and ankle centers worked out by iON were examined by comparing them with centers in real by adapting a circle on the image of fluoroscope during surgery. The final contribution of those errors to the mechanical axis of femur and tibia was evaluated respectively.
Results: The centers of femoral head estimated by passive motion deviated 35.8±36.7 % of radius relative to the center in actual, which cause errors in femoral mechanical axis 0.8±0.7° (max 3.0 °). Overall the deviation of axis was within 1 ° except one case that was performed for the first time after introducing this system. Since ankle centers registered automatically were revealed to shift medially without exceptions, the error of tibial mechanical axis was more than that of femur (1.3±0.4°, max 2.0°).

Discussion: Generally we believe that the accuracy of navigation system had been already verified by cadaver studies performed by manufactured companies. Since the deformities of skeletal structures, obesity, and the bowing of femur and tibia might influence the accuracy of calculated center of joints, we considered that the fidelity of mechanical axis has to be evaluated by comparing to those determined in the images by surgeons themselves. Our data illustrate that reliability of mechanical axis of femur were acceptable since the errors were within 1 ° mostly. To the contrary the accuracy of centers in ankle should be improved further since the errors were beyond 1 ° in most cases, which is speculated to be arisen from software program (Ver.1). Actually the software was updated later (Ver.2). We are going to examine the reliability of this new program in the future. In addition we only investigated the accuracy at coronal axis in this study, the accuracy of a sagittal mechanical axis still remains to be elucidated later.
ORMIS: A Miniature Orthopaedic Robot With Registration From Two C-frame Images

FINLAY PA1, MORFEY S1, DANDACHI W2, AMIS A2

1 Prosurgics Ltd, High Wycombe, UK
2 Imperial College, London UK

pfinlay@prosurgics.com

First generation orthopaedic robots were large and costly. They offered accuracy but required lengthy planning and registration activities. A new generation of robotic devices is now appearing that is smaller and less intrusive into the surgeon’s workflow. ORMIS is a prototype orthopaedic robot of this type, intended for routine use in trauma and elective procedures that require accurate straight-line insertion of guide wires, pins, screws etc. Examples of procedures are Dynamic Hip Screw guide wire placement, distal locking of femoral intramedullary nails and drilling of the femur and tibia for ACL replacement.

ORMIS in use
The ORMIS robot prototype is a 4 degree of freedom manipulator approximately 20cm cube with a limited working envelope. It clamps to the operating side rail on an adjustable slide that allows the surgeon to place it in approximately the desired position. The robot is connected by cable to a workstation positioned conveniently for the surgeon. The workstation consists of a conventional PC with a touch screen allowing a gloved surgeon to interact with it either by covering the screen with a sterile drape or by using a sterile pointer.

To use ORMIS, no pre-operative imaging or planning is required. To register the robot, a registration guide is placed in the toolholder. The guide contains 5 X-ray bright spheres. Two approximately orthogonal C-frame fluoroscopy images are taken, such that both the surgical site and the registration guide are included in each image. The two images are captured via a frame grabber and displayed in turn on the touch screen. Thus the surgeon is able to see both the bone to be operated on and the 5 registration balls in each image. The surgeon is prompted to mark the position of the balls by touching the screen, and then
to draw a line on the bone image which starts at the entry point and ends at the intended target. There is now sufficient 3D information available for the robot to know its position in space relative to the planned line, and thus registration has been achieved. The ORMIS controller calculates the required tool insertion depth and displays this on the screen so that the surgeon can set the tool end stop manually. When the surgeon is ready, the ORMIS screen switches to robot control mode. The surgeon removes the registration guide from the toolholder and replaces it with a sterile guide cannula. The surgeon presses a button on the touch screen to activate the robot, which will then move in 4 axes (X, Y, pan and tilt) to orient the cannula so that it is aligned with the drilling trajectory specified on the plan. The surgeon then inserts the drill or guide wire through the guide cannula into the bone, and drills until the end stop is reached. The drill tip is then on the surgical target, and confirmatory X-rays can be taken if required.

Technical details
The robot articulation is designed to prevent unintended damage to the patient through collision. Therefore no axis of motion is provided to move the robot towards the patient (Z direction). When it is first set up, the surgeon positions the robot conveniently close to the anatomy, and the intervening distance is covered by the calculated tool insertion depth.

The registration algorithm is based on an optical model, and assumes a point source conical X-ray beam. The distance from source to image intensifier plane is calculated from measurements on a cuboid calibration block, and this parameter is stored in the ORMIS workstation. Fluoroscopy X-ray images are known to exhibit pin cushion distortion, and we have a method for correcting for this using a calibration grid. However in trials to date this distortion on the two C-arms we have used has not been material to our results. The registration algorithm is not dependent on orthogonal images, but the accuracy of surgical planning is improved if the two views are at 90 degrees.

Practical experience
To date the robot has been tested on a DHS guide-wire drilling procedure using a limited set of saw bones models. Our intention is to move to cadaveric trials and then clinical studies. We have measured the accuracy by pre-drilling a hole in the saw bones femur, and then placing an X-ray opaque metal pin in this hole. When the bone is imaged, the pin clearly shows as a dark line. When the surgeon plans the operation he specifies this line as the required trajectory. When ORMIS is then instructed to move to the operational position, it is easy
to if the cannula is correctly aligned with the planned target simply by passing a
guide wire through the cannula and checking that it passes into the pre-drilled
hole.

Early results have indicated that the ORMIS manipulator accuracy is within
the target of being able to place a guide wire at a specified tip-to-apex distance
in the femoral head with an error of no more than 2mm. We are currently
conducting further studies to report quantitative results from a number of trials.
The manipulator requires to be placed within a few cm of the target manually,
but we plan to relax this requirement by increasing its translation range. We
are also planning to re-design the registration guide to make it less obtrusive,
and enable more flexibility in C-arm positioning. In time we plan to automate
the detection of the registration guide, and to provide the user with graphical
assistance to eliminate discrepancies in start and end point specification
between AP and lateral images.
This paper introduces a new method for navigated spine surgery using a stereoscopic video see-through head-mounted display (HMD) and an optical tracking system. Vertebrae are segmented from volumetric CT data and visualized in-situ. A surgical drilling device is virtually extended with a mirror for intuitive planning of the drill canal, control of drill direction and insertion depth. The first designated application for the virtually extended drilling device is the preparation of canals for pedicle screw implantation in spine surgery. The objective of surgery is to install an internal fixateur for stabilization of injured vertebrae. The system was tested by five surgeons in a phantom study of lumbar vertebrae. We compared the new approach with the classical, monitor-based navigation system providing three orthogonal slice views on the operation site. We measured time of procedure and scanned the drilled vertebrae with CT to verify accuracy of drilling.

We suggest dividing the procedure of drilling pedicles into two steps. First a drill canal is planed and defined, second the drilling itself is performed. Virtual components of the AR scene include a polygonal surface model of the vertebrae, a red arrow supporting the interactive planning of the drill canal, the virtual mirror and a blue cylinder representing the tracked drill. Depending on the position of objects, a virtual model of the drilling device is visible in the mirror image. The model of the drilling device is used to create a depth mask with the stencil buffer to provide occlusion, when the drilling device is positioned between the observer and visualization of segmented vertebrae or the virtual mirror. The red arrow is initially orientated to the drill direction and positioned at its tip. The surgeon moves the drill to the visible entry point on the vertebrae and orientates the read arrow to the optimal drill canal. To ensure the correct position of the drill canal, the mirror is used to provide side views of the semi-transparent vertebrae. The mirror can be rotated on a circular path.
around the drill axes (radius=10cm) by rotating the drilling device around its axes. For ease of use the rotation angle of the drilling device is multiplied by an adjustable factor to change the position of the mirror. This enables the surgeon to move the mirror around the target while only rotating the drill by small angle. Thus only slight motion of the drilling device provides all desired side views.

When the canal is positioned correctly, it can be locked. It will then remain at a fixed position inside the vertebrae during the following steps of the procedure. Once the canal is defined and locked the mirror automatically moves to a position in front of the drill, orthogonally to the drill direction. Now the exit point on the bottom of the vertebrae but also allows for control of depth insertion. The mirror can be positioned automatically. However, we suggest to let the surgeon define its position according to the particular scenario, e.g. pose of the patient, position of equipment, surgeon and surgical staff during the operation and position of the operation site. When the ideal position for the mirror is found, it can be locked and remains respective the vertebrae. A virtual spot light is attached to the drill tip and orientated to the drill direction. The non-realistic behavior of spot lights in OpenGL here turns into an advantage. Spot lights are not blocked by surfaces. Even surfaces not visible for the light source are illuminated, if they are located inside the cone of the spot light. Therefore the spot light illuminates the entry point at the pedicle as well as the exit point on the opposite side of the vertebrae, which is visible only through the mirror. Regarding the surgical task, the drill has to be aligned with the defined drill canal at the entry point using visual cues due to the spot light and intersection of drill, vertebrae and drill canal. Thereupon the drill has to be reoriented until the visible spot light is aligned with the exit point on the back of the vertebrae seen through the mirror.

We asked five surgeons to drill preparative canals (Ødrill = 4mm) for pedicle screw implantation into the two replaceable lumbar vertebrae. We then compared a classical monitor based navigation system with the present method. Regarding navigated drilling for pedicle screw implantation, three of the surgeons were highly experienced, one had low experience and the last one had no experience. Furthermore all of them had been exposed to our system within the scope of a different evaluation study. In real surgery the surgeons prepare the pedicles to avoid gliding off and injuring anatomy before they start drilling. In this experiment, however the surgeons start drilling directly into bones.

Each subject has to consecutively drill four canals using each method. Overall, we analyzed quality of 20 canals for each method and measured time of the procedure. Regarding the duration of drilling one canal, using the classical monitor based method is faster than the proposed method. This time lag is due to the fact
that the present method requires a planning phase. This is not intended for the classical navigation system. However when comparing the quality of drill canals our method proves to be more accurate (see table).

<table>
<thead>
<tr>
<th>method</th>
<th>mean</th>
<th>std. deviation</th>
<th>std. error mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>accuracy</strong></td>
<td>1.35</td>
<td>0.75</td>
<td>0.17</td>
</tr>
<tr>
<td>virtual mirror</td>
<td>1.7</td>
<td>0.86</td>
<td>0.19</td>
</tr>
<tr>
<td>monitor based</td>
<td>168.95 sec</td>
<td>103.59 sec</td>
<td>23.16 sec</td>
</tr>
</tbody>
</table>

This paper introduces a new method for navigated spine surgery using an augmented reality system. Medical imaging data is visualized and presented with a stereoscopic video see-through HMD. The virtual part of the AR scene is extended by a virtual mirror to support more intuitive visualization and more accurate navigation. Furthermore five trauma surgeons tested the method with an experimental setup. Analysis of measured data proves the system to be promising both in terms of accuracy and usability.

References

A Fluoroscopy-guided Robotic System
For ACL Reconstruction

HU Y¹, WANG TM¹, WANG JC¹, SUN L², LIU WY¹, WANG YW¹, FENG H², WANG MY²

¹ Robotics Institute, Beihang University, Beijing, China
² Beijing Institute Of Traumatology And Orthop., Jishuitan Hospital, Beijing, China

buaarobot@126.com

Introduction: The rupture of Anterior Cruciate Ligament (ACL) is one of the familiar sport injury, and the functional failure-rate of ACL can reach up to 8%, even 25%. It is very difficult in the confirmation of graft tunnel in the field of traditional arthroscopic surgery¹

The development of medical robots is a dynamically growing discipline in the field of both the medical application and the technical challenge.² Robot-assisted navigation can provide effective means to solve problem above because it can improve the operation positioning, and it is more steady and credible than the manual operation. The aim of this work is to introduce a robot-assisted ACL reconstruction navigation system with fluoroscopy developed by ourselves. Some experiments including 10 plastic bones (Synbone, Swiss) and 5 animal bones have been performed with this system.

Materials and Methods: The system is initially designed to assist the surgeon to carry out the surgical planning, the entry positioning and drilling of implant tunnels, the anisometry measurement, and eventually to validate performances during the apparatus tracking, the target positioning, the joint kinematics evaluation. There are several modules such as the image acquisition, the image dewarping, the C-arm calibration, MicroTracker2.7 camera based on video, NDI camera on based photoelectric, passive robot of 5-DOF, operation controlling platform, intraoperative bone surface reconstruction and virtual simulation in this system, as shown in Fig.1.¹ The surgical planning is performed on the front and lateral fluoroscopic images. The theoretics is the 46%-based tibial and quadrant-based femoral entry planning which are identified in medical field
universally. The navigation tracking module consists of the visual light vision sensor MicronTracker2.7 (MT) and the infrared photoelectric sensor NDI Polaris. The advantages of two tracking modes are exerted in this system. The surgeon can get intuitionistic and credible results because real-time information about the operation environment and the instruments are acquired by MT. The quality of bone surface reconstruction have been improved and accuracy of navigation after the NDI is applied in implementing the mapping of several coordinates in the operation environment, and reconstruction of unorganized points collected on the geometrical surface of bone. In order to meet the requirement of exact manipulation in ACL reconstruction, 5-DOF passive robot which assists the surgeons entry positioning and drilling of implant tunnels, implementing exact manipulation in knee joint have been implemented. The operation security of assisted robot is improved because its mechanism adopts configuration PRPRR and its workspace and position adopts step control. Passive robot and video camera has been installed on the control platform.

Results: Some experiments on 10 plastic bones (Synbone, Swiss) and 5 animal bones including the navigation assistance in entry planning of tunnels, the real time tracing of surgical apparatus and the end of robot, the individualized surface reconstruction of knee joint, the virtual simulation of the impingement, and anisometry evaluation of reconstructed ACL were implemented. The accuracy tests give out a resulting positioning error less than 1.6 mm.

Discussion: This is a new ideal that the visual light vision sensor MT is used in the operation. MT can monitor the information of all objects in the operation environment in real time and can provide the surgeon with intuitionistic vision. However, its accuracy of tracing and lack of enough stability to the light variation cannot fully meet the request of ACL reconstruction operation. Although the infrared photoelectric sensor NDI cannot provide real-time video
of the environment, it can improve the tracing accuracy of operation and it has enough stability which can make up the disadvantage of MT.

Currently, the research on the rehabilitate robot about sports trauma is in the beginning phase. The typical systems include CASPAR, RSPR3, ACROBOT, and other type of robot system. Introduction of computer and robot can assist the surgeon to manipulate in the narrow space, improve the positioning and operation accuracy, and realize the minimally invasive surgery. The accuracy can achieve 1-3mm if the computer assisted navigation is used in ACL reconstruction, while it can achieve 0.5mm if the robot is used. Under the direction of this ideal, 5-DOF passive robot has been designed and developed to assist the surgeon to perform the entry positioning and drilling of implant tunnels in order to satisfy with the high accuracy demand and the narrow operation space of ACL reconstruction.

15 experiments have been implemented successfully with this system. The feasibility of surgical planning on the front/lateral fluoroscopic images and the accuracy of the implant entry positioning navigation in the tracing with NDI has been validated by these experiments. In conclusion, the location accuracy has reached the leading clinical standard of the leading navigation system. What’s more, there is still some development space for improvement which will be further investigated in future.

References

In Vitro Robot Assisted Bone Resection For Total Knee Arthroplasty - An Orthopedic Surgeon’s Experience

Hung TSS1, Yen PL2, Lee MY3

1 Department Of Orthopedic Surgery, Tzu-chi General Hospital Taipei Branch, Taipei, Taiwan
2 Graduate Institute Of Automation Technology, National Taipei University Of Technology, Taipei, Taiwan
3 Graduate Institute Of Mechanical Engineering, Chang-gung University, Taoyuan, Taiwan

hung_ortho@yahoo.com.tw

Introduction: Precise bone resection in total knee arthroplasty is the crucial step for obtaining a good alignment. Although several navigation systems have been in the market for years, most of them only provide the information on the location and direction for bone resection, and the surgeons still have to do the bone resection by hand, which may still leads to some degree of inaccuracy due to hand shaking. We have designed a novel surgical robot for bone resection intended for total knee arthroplasty, and the preliminary experience on the cadaver knee is presented.

Materials and Methods: The arm of surgical robot was designed to move in three directions perpendicular to each other, and the end effector was designed to be able to rotate on a single axis, while the cutting of bone was performed by a high speed rotating drill bit. After registration of the bony landmark with a 3-D digitizer (MicroScribe®), the size of implant was decided automatically, and the amount of the bone to be resected, as well as the planes of resection were calculated. The knee joint had to be fixed steady after well exposure, and the arm of the robot would be driven by the step-motors to the cutting planes. As the tip of the end effector was in the position, the surgeon would now drag the end effector horizontally to complete the bone resection under a constrained space provided by the robot. The experiment was conducted in the Tzu-Chi “Silent Mentor” surgical simulation lab on the knee joint of a cadaver, and the exposure was obtained via a medial arthrotomy as in a conventional total knee
replacement surgery. Since the system was not yet fully completed, only the femoral resection was carried out.

Results: During the registration process, the digitizer was attached to the distal shaft of femur, and the center of hip joint was obtained by performing circumduction of femur. The Whiteside lines, anterior cortex of distal femur, surface of both medial and lateral femoral posterior condyle, and the tip of both medial and lateral femoral epicondyles were identified with the digitizer as well. In this experiment, the power driven end effector was able to travel at a steady speed while doing the bone cut, and a flat smooth cutting surface was obtained as planned. Off track cutting was intentionally attempted during the procedure, and the apparatus was able to keep the surgeon away from severing vital structures.

Discussion: The registration process was simple and quick with the digitizer, and there was no problem with data collection, as that often occurred when using infrared navigation system. The force sensor incorporated at the end effector allowed a feedback mechanism during which the traveling speed of the cutting tip would be slowed down when going through a harder bony structure, in order to obtain a more smooth surface. However, there are still some improvements needed to be modified. The cutting tip was traveling in a horizontal path, which was not practical in some circumstances due the limitation of wound exposure, thus multi-directional approach was suggested. Before moving to another cutting plane, the end effector was designed to return to the origin via the same path, which was considered to be a redundant step. This was a preliminary experiment with a novel design of surgical robot. From an orthopedic surgeon’s point of view, the apparatus was superior to the traditional total knee surgery in the way that it was gigless, and could provide a more accurate bone cut with a safe margin.
Introduction: Orthopaedic oncology, the treatment of bone tumors, is a challenging field within orthopaedic surgery. Often large resections are done and locations can be difficult. Surrounding structures can be at risk, so in orthopaedic oncology precision is important. Computer Assisted Surgery (CAS) may enhance precision. There is hardly any experience with navigation in orthopaedic oncology. The role of computer navigation here is yet unclear. We present our first 10 patients with bone tumors in whom CAS was used as an adjunct to enhance precision.

Purpose: To evaluate and report our first experience with CAS in orthopaedic oncology. Does it bring precision, efficacy and safety in orthopaedic oncology. Is it necessary to use CAS? In which cases does it help? Is it worthwhile continuing?

Materials and Methods: In the past two years 10 patients were treated for bone tumors in different locations of the skeleton with the aid of CAS. Complications, an estimation of additional operating time and usefulness of CAS were monitored.

Results: In 9 of 10 patients CAS was successfully employed. The tumors were all removed without complications. Operating time is extended with 15 minutes. CAS was not necessary in 5 of 10 patients. It has a definitive additional value in resection of tumors in difficult locations (e.g. pelvis).

Discussion: CAS can be a successful adjunct in orthopaedic oncology. It adds precision, is effective and safe. The indication area needs further study.
Automated 2D/3D Image Matching Method With Dual X-ray Images To Estimate 3D In Vivo Knee Kinematics

Kim YH, Le DP, Kim K, Park WM

1 Department Of Mechanical Engineering, Kyung Hee University, Yongin, Korea
2 Institute Of Natural Sciences, Kyung Hee University, Yongin, Korea

kyungsoo@khu.ac.kr

Introduction: In the knee joint surgery such as total knee arthroplasty, the implant should be inserted in proper position with correct bone alignment because the abnormal kinematics of implanted knees by implant mal-positioning or mal-alignment could cause failure of surgery. Therefore, quantitative information of a three dimensional kinematics of the knee joint is very helpful to evaluate the surgical treatment such as planning of size and alignment of the implant. Since retaking CT or MRI with regard to each pose of knee joint needs additional cost and time, 2D/3D image matching methods using dual X-ray images have recently been introduced to analyze the in vivo joint kinematics [1]. However, the image matching methods in the previous studies were performed manually, thus an automated image matching method could be necessary to reduce the analyzing time and operator dependency. In this study, a 2D/3D image matching method was developed to estimate the kinematics of the knee joint based on an automated pixel by pixel comparison of images. The accuracy of the present method was validated by an experiment with a 3D cubic phantom in a known position and orientation.

Materials and Methods: Two projection images were obtained from the 3D object in two perpendicular directions where the given dual X-ray images were taken. These projection images were compared with the given X-ray images. The 3D object was translated and rotated automatically and continuously until its projection images were matched with the X-ray images in a given tolerance range. The optimization algorithm was used to minimize the root mean square error between the gray scale values of each pixel in the projection image and the given X-ray image. In order to validate the accuracy of the developed
2D/3D image matching method, the image matching of a cubic phantom was performed. For estimating the position and orientation of the knee joint, the 3D knee joint models were reconstructed from CT data. Then, the 3D model was matched with the given dual X-ray images by using the developed 2D/3D image matching method. With the obtained result for each component, the tibial and femoral components were then combined into the whole knee joint model. By adding fiducial markers based on clinically conventional method in knee joint, the posterior and mediolateral translation of femur with respect to tibia as well as the flexion angle were measured.

**Results:** In the experiment with the cubic phantom, the position errors were below 0.10 mm and the orientation errors were below 0.05° when using dual X-ray images. With a single image, the position errors were below 5.0 mm and the orientation errors were below 3.1°.

For the given dual X-ray images, the relative in vivo kinematics of the femur was measured as the posterior translation was 3.0 mm and the mediolateral translation was 0.9 mm. In addition, the flexion angle of the knee joint from the sagittal view was 51° while the angle measured from the given X-ray image was 50°.

**Discussion:** In this study, an automated 2D/3D image matching method was developed to estimate the position and orientation of femoral and tibial components from dual X-ray images. The estimated result was used to determine the in vivo kinematics of the knee joint. Since the abnormal kinematics of the knee joint could influence the surgical outcomes, accurate estimation of in vivo kinematics of the knee joint would be valuable for pre-operative planning and post-operative evaluation.

X-ray images have been clinically used to find the 3D in vivo knee kinematics. First, 2D/3D image matching method by using a single X-ray image have reported, however, those methods have a limitation of methodology in detecting out-of-plane translation and rotation though the in-plane accuracy was acceptable. Hence, dual images have been recently used in the matching method to improve the out-of-plane accuracy [1]. The accuracy in this paper was comparable with the previous literatures.

The previous 2D/3D image matching methods were operated manually [1, 2]. Though the accuracy of those manual matching methods by a well-trained operator was acceptable, the matching process took long time and was dependent on the skill and condition of each operator. Recently, automated image matching method has developed by applying optimization algorithms based
on the comparison of the boundary of images [3, 4]. In this study, the optimal position and orientation were obtained by the direct pixel by pixel comparison, which are easy to implement and modify the algorithm. The present automated method could accelerate the matching process and stabilize the repeatability. The 2D/3D image matching method in this study is a powerful tool for the accurate determinations of 3D position and orientation of the knee joint and could provide informative characterization of implant designs and surgical options of the knee surgery. The advantages of our study are the accurate estimation of the 3D knee joint kinematics including out-of-plane motion by using dual X-ray images and the automated process by the optimization algorithm. Furthermore, the present method could be applied to the studies about 3D dynamic in vivo kinematics of other musculoskeletal joint.

References


Time And Cost Savings With Navigated Total Knee Replacement

KIRSH G

St George Private Hospital, Sydney Australia

george@gijkirsh.com

Computer navigation is currently thought of as time consuming and costly. We have been using navigation with total knee replacement for nearly five years now and have found operative times to be equitable with intramedullary systems. A new system of setup has been employed with navigation with a view of saving both time and sterilizing costs. Original discussions with Stryker ended in the company working on a disposable system. We decided to work with Stryker Australia to pursue a reusable, environmentally conscious system.

Times taken to perform different aspects of theatre time were measured to see where time was taken in a routine navigated total knee replacement. These were divided into anaesthetic time, setup time, operating time and clearing time. Setup time was always more than anaesthetic time and, as such, would delay the start of the anaesthetic be it spinal or general anaesthetic.

Original Stryker trays for a navigated total knee replacement were setup in 13 full trays containing 276 pieces. We sorted all the instruments used in every case into 2 full trays and 3 small trays (1/3 size). All trials and femoral cutting blocks were then packaged in size specific, small trays as well. Only the correct femoral and tibial trial prostheses were opened - obviating the need to sterilize ALL of the trials for each case. A separate two trays are available on the shelf containing non-routine instruments.

We found setup times prior to using the new system was 20 to 30 minutes and the theatre was cramped with trolleys. With the new trays, setup time is less than 5 minutes - less than the time for insertion of a spinal anaesthetic. With the reduced tray load, fewer trolleys are required in the operating theatre as well. As there are less trays, routine staff and scrub staff less familiar with the Scorpio instrumentation were able to find instruments quickly thus reducing operating time as well.
Because the popularity of the new setup system in the private hospital central sterilisation and supply department, we now also use it in the public hospital. Less knee replacement kits are needed when multiple knee replacements are performed in one day as a setup can be turned around in the time another knee replacement is performed. This reduces the need for more kits being shipped to the hospital and less kits needed by the supplier.

Sterilising costs are calculated on a weight basis. We calculated the cost of sterilising the the setup trays for a routine total knee replacement provided by the manufacturer and then the cost of sterilising the new instrumentation. Reducing the number of trays and instruments reduces the weight of packs needed to be sterilised. The sterilization cost savings with the new system has been calculated at $AUS 1100 per case. When this is added to the saving of 15 to 25 minutes of theatre time (at $AUS 50 - 100 per minute), there is no doubt that computer navigation with total knee replacement is cost effective.
Computer-assisted Mosaicplasty

Kunz M1, Rudan JF2, Bardana D2, Stewart J1, Waldman SD3, Ellis RE4

1 School Of Computing, Queen’s University, Kingston, Canada
2 Department Of Surgery, Kingston General Hospital, Kingston, Canada
3 Department Of Mechanical And Materials Engineering, Department Of Chemical Engineering, Queen’s University, Kingston, Canada
4 School Of Computing, Queen’s University, Department Of Surgery, Kingston General Hospital, Kingston, Canada

kunz@cs.queensu.ca

Introduction: Damaged articular cartilage in weight-bearing areas of the knee is not only painful for the patient, but also limits the Range of Motion (ROM) and therefore has a great effect on the patient’s quality of life. Because articular cartilage has a limited self-healing potential, surgical treatment is necessary to restore the cartilage surface. The transplantation of multiple autologous osteochondral plugs (mosaicplasty) is one well accepted technique. During this procedure, small osteochondral plugs are retrieved from the periphery of the femoral or the margin of the intercondylar notch and transplanted into damaged regions. For long-term success of this procedure, the transplanted plugs should reconstruct the curvature of the articular surface. To fulfill this requirement, many parameters including size, height, position, orientation and rotation of the plugs, as well as number and pattern of the plugs must be considered. The goal of this project was to develop a computer-assisted system to help the surgeon to achieve high accuracy in these complex mosaicplasty procedures.

Materials and Methods: 3D image modalities (CT, MRI) were used to reconstruct the knee’s bony anatomy, cartilage thickness, and an outline of the cartilage defect. A 3D model of the knee was computed, containing a bone model and a transparent layer of cartilage. The damaged cartilage region was then virtually restored by modifying its cartilage. This modified model was used as the template for preoperative planning of mosaicplasty, performed using custom-made software. For each plug, the user was able to modify radius, height, position and orientation in retrieving and receiving areas (figure 1). A graphical user interface allowed the surgeon to evaluate the planning.
To transfer the final plan into intraoperative use, a patient-specific, sterilizable, plastic template was created using a rapid prototyping machine. This template included a mirror image of the articular surface of the knee. The surgeon used this mirror image to position the template on the knee, thereby ensuring a precise transformation of the preoperative plan into the intraoperative situation. For each plug, two instrument guides were incorporated in the template (figure 2). On the retrieval side, the guide positioned and oriented a conventional plug cutting instrument with respect to the planning. To ensure the planned height of the plug, a predefined height mark on the cutting instrument was aligned with the top edge of the guide. In the similar way, the guide on the receiving side navigated the tools for preparation and transplantation of the plug into the damaged area. Both guides were designed with instrument alignment marks to ensure that the rotation of the plug followed the planned curvature of the articular surface.

We performed the above described procedure on one patient, with a cartilage defect of 2x3 cm on the medial site of the knee. Nine autologous osteochondral plugs were planned preoperatively (figure 1). The diameter of planned plugs varied between 4 mm and 8 mm. For intraoperative navigation, three patient-specific guides were produced. Each of these templates guided the harvesting and insertion of 2-4 plugs (figure 2). The procedure was performed using the COR system (Depuy Mitek Inc., a Johnson and Johnson company, Warswa, USA).

Results: All templates were applied successfully during the surgery. Harvesting and preparation of the receiving site was performed as per the preoperative plan. Fixation of the plugs with smaller diameter were judged to be difficult by the operative surgeon.
Discussion: The time-consuming and complex geometrical problem of reconstructing the articular cartilage surface using multiple autologous osteochondral plugs was solved by the surgeon using this virtual preoperative planning tool. Intraoperative guidance using individual instrument templates provided a time-efficient, accurate, cost-effective and easy to use method to intra-operatively perform the plan. However, the use of these templates demanded a complete access to the knee during surgery. Further research in the area of minimal invasive methods for intraoperative guidance needs to be performed.

The problem of fixation of plugs with small diameter also needs further investigation. The virtual planning tool can potentially be used to find an optimal solution that avoids or minimizes the use of smaller diameter plugs. Also, a larger bony part for smaller plugs could reduce the fixation problem.

In conclusion, our early experience with this technique inspire us for further research in the application of computer-assisted techniques for mosaicplasties, to unlock the possibilities of this technically highly demanding procedure.
Surface Modeling Of Multiple Bone Objects By Staged Self-organizing Map Neural Network

LIN H

Texas Scottish Rite Hospital for Children, Dallas, TX, USA

honglin999@ieee.org

In this paper the surface modeling of complex (ill pose) bones by the Self-Organizing Map neural network is introduced for the purpose of intra-operative fluoroscopic image guidance and monitoring. Self-Organizing Map, an unsupervised network is employed on the three-dimensional mesh of globe. The pointclouds are obtained by delineating the interested bone outlines on each slice of MRI or CT images. Depending on the complex of bone structure, each bone segment can be modeled by either one step or two step unsupervised network training.

Introduction: Preoperative treatment planning for Computer Assisted Orthopedic Surgery requires 3-D bone modeling. In the Virtualized Reality environment [1] the complex bone objects are modeled and manipulated to simulate the procedure and predict the outcome of operation. There are several 3-D object modeling approaches proposed including surface modeling, solid modeling and procedural modeling. The surface modeling can be made by the methods of statistical modeling, supervised neural network and unsupervised neural network modeling [2]. In this study, a multi-staged unsupervised neural network approach has been experimented, i.e. the Kohonen Self-Organizing Map (SOM).

Materials and Methods:
A. Pointclouds Acquisition and Model Initialization
Pointclouds of bone objects were created by delineating the interested bone outlines on each slice of MRI or CT images. Order of the pointclouds is not significant since the points would be used in the randomly bases. Model was initialized by a globe of 3-D meshes. Each node on the mesh would compete...
with its neighboring nodes in terms of the distances with randomly selected pointclouds, as explained as follows.

B. Self-Organizing Map Modeling
The Self-Organizing Map (SOM) proposed by Kohonen is a one layer network. During the learning phase, neighboring neurons in a 2-D array compete and their connected weights are updated, as for (1), \( W_{ij}(t) \) is the weight element of neuron \( j \), \( \alpha(t, \text{dist}_{ij}) \) is the topologic distance between the winning neuron and neuron \( j \) and the \( x_i(t) \) is the input vector.

\[
W_{ij}(t+1) = W_{ij}(t) + \alpha(t, \text{dist}_{ij}) * (x_i(t) - W_{ij}(t)) \quad (1)
\]

In this SOM surface modeling, the weights are initialized as a globe of 3-D meshes in a 2-D array and the input vector of \( x(t) \) is updated randomly by each point in pointclouds. It should be aware that the 2-D array does not mean it is in a 2-D space. Each of elements in this 2-D array has three components (x, y, z) in 3-D space [3].

C. Staged Neural Network Training Approach
Two-stage surface modeling was tested for a complex shaped bone object (ill posed). For example, for the thoracic vertebra modeling, it is difficult to achieve result from one stage modeling. However, it is feasible to model a less ill posed lumbar vertebra in first stage using the corresponding pointclouds. In the second stage, lumbar vertebra model is used as initial model setting. With thoracic vertebra pointclouds a reasonable result can be achieved [4].
Results: The results are illustrated in Fig. 1. The Fig. 1(A) shows surface modeling of multiple bone segments for knee joint, which include distal femur, proximal tibia and fibula as well as a patellar. Fig. 1(B) shows a proximal femur and Fig. 1(C) shows lumbar vertebra modeling by one stage SOM. Fig. 1(D) is thoracic vertebra modeling by two stage modeling.

References
A Portable Trauma Tele-treatment System Prototype For Anti-terror Emergency Care

LIU WY¹, JIANG JY², WANG YW¹, FANG LM², WANG TM¹, HU L¹, HUANG N²

¹ Robotics Institute, Beihang University, Beijing, China
² Second Hospital Of Beijing Municipal Corps, Chinese People’s Armed Police, Beijing, China

wyliu@263.net

Introduction: The terrorist attack to military or civilian targets always results in the mass of casualties in which the trauma is one of the major injuries. The effective rescue to the wound in the gold hour, even the gold minute is essential to increase the lifesaving rate and the recovery quality. With the idea that bringing the operating room (OR) to the patient rather than the patient to the OR, the instantaneous treatment mode at the patient site is emerging. This mode can set up the treatment environment quickly at or near the place the wound happened and treat the patient under the guidance of expert at the remote site through the network communication. with this mode, this paper proposes a portable tele-treatment system prototype for anti-terror emergency care.

Materials and Methods: System setup
The concept of functional modularization is adopted to design the system architecture, which makes it possible to assemble the desired surgical setup quickly from the set of functional modules according to the specific trauma indication requirements. Therefore we can carry out multiple indications during the emergency care through the different configuration of modules. The system is partitioned into 5 modules: (1) The mobile carrier which is used to contain all kinds of other surgical devices in this system. During the emergency deployment of anti-terror operation, an emergency care platform (i.e., a simplified digitalized operating table with communication interfaces) can be quickly set up with the stretched carrier as the operation table. In order to improve the portability of the entire system, the carrier is designed with the case structure which partitions the inner space of carrier into multiple
smaller rooms to contain devices. The total occupation and operation space of this platform is $2 \times 0.5 \times 1.3$ meters, which is portable and can be deployed in an emergency care vehicle. (2) The compact modularized surgical robot which is used for assisting the surgeon to implement the accurate target-positioning and the dexterous surgical operation. Currently the bi-planar structure is adopted as the mechanism which can enhance the robot rigidity and expand the dexterous space. The local close-form control structure is adopted to simplify the control flow without loss of safety. This robot has been manufactured and validated in clinical applications \cite{1}. (3) The automatically assistant devices which are used for implementing the auxiliary actions of surgery such as the patient fixation, the bone reduction, the device holding, even the gantry rotation of C-arm fluoroscopy. In order to satisfy the unstructured clinical environment, each device in this module adopts the single Degree-of-Freedom mechanism which is simple and safe for the usage. (4) The remote tele-planning module which implements the surgical planning, the virtual simulation, and the video monitoring with graph overlay. The detailed planning may slightly differs from different trauma indications. (5) The network communication module which is designed to transfer information data between the patient site and remote site. The typical data are the intraoperative X-ray images, the real time monitoring video stream and the control data. In LAN, the TCP/IP-based Client/Server mode is adopted to transfer the video and the planning data between the both sites. In WAN, multi-ADSL/MODEMs technique is adopted. And the concept of tele-planning is introduced to deduce the transfer loads and increase the efficiency. At the patient site, the local wireless communication is adopted to improve the mobility.

Operation procedure
The preliminary procedure is designed as following: (1) Set up the trauma emergency treatment platform near the wound; (2) Acquire the information data about the patient with the imaging devices (the fluoroscopy, the CCD, etc.) and then transfer them to the remote site; (3) The surgical planning is made out by the expert based on the received data and fed back to the patient site; (4) Assemble the robotic device from the functional module set and carry the trauma treatment under the guidance of the planning result. As the first trial, we have tested the system in the fracture reduction and intramedullary nail locking with the tibial model.

Experiments
5 cases of plastic tibial bones (Sybone, Swiss) with the fracture reduction and nail locking are tested under the LAN communication within 500 meters. The
bi-planar robot is used for the target positioning. Currently a C-arm (Philips BV Libra) is used for the fluoroscopy imaging at the patient site. The sensor MicronTracker2 (Clarontech, Canada) is used for the target tracking. Data about the time delay of network communication, the robot positioning accuracy, and the operation time are recorded.

Results: The time delay of network communication in LAN is less than 500 ms. The robot positioning error is less than 0.8 mm. The operation time for reduction under the video monitoring is about 5 minutes. The operation time for nail locking including the planning is less than 15 minutes.

Discussion: The R&D and application of robotic and telepresence device is receiving more and more focus in anti-error emergency care. Since the 1990s, U.S. Department of Defense and the NASA have sponsored many projects such as the Green Telepresence Surgery System from 1994 and the Trauma Pod project form 2005 [3]. Some new ideas (e.g., automation, portability, modularization, etc) therefore are being introduced into the development of the emergency care device. This kind of device provides the surgeon with the tele-controlled automatic measures, thus can provide the effective emergency care service in anti-terror environment. This paper preliminarily investigates the technical feasibility of this kind of system. In the next step, the system performance and
Technical Innovations & New Applications

the clinical feasibility will be further evaluated. The more effects will be done on the amelioration of robot configuration, the improvement of communication efficiency, the friendly human-machine interface, and the regulation of the operation procedure in the practice.

References


Pose Recovery Of Intramedullary Nail Distal Hole Using Neural Networks

LORSKUL A¹, U-THAINUAL P¹, MAHAISAVARIYA B², SUTHAKORN J¹

¹ Department Of Biomedical Engineering, Center For Biomedical And Robotics Technology, Faculty Of Engineering, Mahidol University, Thailand
² Department Of Orthopedic Surgery And Physical Medicine, Faculty Of Medicine, Siriraj Hospital, Mahidol University, Thailand

g4936224@student.mahidol.ac.th

Orthopedic surgery is an important treatment concerned with injuries, trauma and other disorders of the musculoskeletal system. Closed Intramedullary Nailing (IMN) of Femur is one of the most frequently used treatments in orthopedics. It has developed into a common method of treatment for femoral shaft fractures. A procedure of fixation named “distal locking” requires a fluoroscopic monitoring for screw locking process. Currently, in this conventional distal hole locking, it uses trial-and-error method to find a correct projected path for inserting the screws. This requires high experience and a numerous x-ray images for randomly adjusting the fluoroscope direction. According to this gradually adjustment, a high amount of radiation scattered to the primary surgeons and patients has been reported in several orthopedic investigation. The concept of the proposed study is to utilize a computer-integrated surgery (CIS) method to guide a surgeon for recovering the correct position and orientation (or “pose”) of the intramedullary nail. The algorithms emphasize on using a neural network approach to recognize and provide rotation angle of the intramedullary nail relative to the image intensifier (fluoroscopic system).

Overall study in x-ray image projection of the distal holes, there are two main possible cases of the obtained images. First, it occurs when the plane of the fluoroscope or C-arm is perpendicular to the nail axis while taking x-ray. Therefore, the distal hole projections can be investigated approximately for only in one axis, “Nail Axis.” The other case happens when the C-arm’s plane is not perpendicular to the nail axis. Therefore, the distal hole projection images are the combination of various rotation angles’ axis. This analysis has to be performed on a Z-Y-X Euler Angle which is much more complex than
the first case. With several utilities of neural networks, various applications employ this knowledge to solve many problems including in medical aspect. Artificial neural networks is one of the effectively techniques that performs in various works, for examples, in pattern recognition, optimization problems, control techniques and so forth for last decade.

In this study, the neural network has been learned about the distal hole projection images in the first case study. A certain series of 2-D images has been fed into an input layer of a multilayer perception network which is operated by back prorogation learning algorithm. Basically, these images are the indifferent in rotation angles of the nail. The significant essence of the images is the shape of distal holes which are both in ellipse and circular shapes. All images have been employed by pre-processing module for extracting important parameters beforehand. Subsequently, sigmoid neuron units in hidden layer have been trained and updated their weights during the learning procedure. A number of output neural units are the same as a number of rotation angles which are fed into the input layer. The appropriate network architecture has been selected by cross-validation approach which is divided a data set into training set and test set. After that the test data set has been loaded in order to verify the generalization ability of the network.

According the preliminary results, the experiment was performed and analyzed accuracy. The rotation angle results which were recognized by the efficient neural network have been measured with respect to the real world orientation. The rotation accuracy is satisfied with acceptable errors for providing the orientation information to the guided system. The pose recovery is obtained using only 2 x-ray projection images. This obtained rotation angle together with the translation vector will be formed a transformation matrix. This information will advise the direction of fluoroscopic system in order to finding the appropriated distal holes of the intramedullary nail. Future task of this study is to mention on the non-perpendicular between the C-arm’s plane and the nail’s axis. The training data will be a combination set of the Z-Y-X Euler Angle. The x-ray images are displayed in a shape with more than one rotation axis. It will
compose of rotation in x-, y-, and z-axis. Moreover, the experiment will be performed the generalization ability of the neural network for different data set of the patients.
A Novel Field-of-view Augmentation Wand For C-arm Ct-like Fluoroscopy-based Intraoperative Navigation

PELEG E1, LIEBERGALL M2, JOSKOWICZ L3, WEIL Y2, MOSHEIFF R2

1 Department Of Medical Engineering, Hadassah University Hospital, Israel
2 Department Of Orthopedic Surgery, Hadassah Hebrew University, Medical Center, Israel
3 School Of Engineering And Computer Science, The Hebrew University Of Jerusalem, Israel

eran@hadassah.org.il

Introduction: Fluoroscopy-based intraoperative navigation has demonstrated its clinically utility in a growing number of orthopaedic surgery procedures. It provides simultaneous, real-time, multiple view instrument profile location visualization on fluoroscopic images, thus significantly reducing imaging radiation, and that, unlike CT-based systems, does not require an additional registration procedure. However, it does not provide true 3D information to the surgeon.

Recently, the mobile SIREMOBIL® Iso-C3D C-arm was introduced to obtain intra-operative three-dimensional (3-D) representation of bony structures, including multi-planar reconstructions. Intraoperative three-dimensional visualization using the Siremobil Iso C3D has been approved for use in spine and long bone surgery. The main disadvantages of the resulting CT-like images are their insufficient visualization quality and limited data volume (approx 12cm³). This has limited its use in obese patients and in pelvic area cases. When combined with a navigation system, true 3D CT-like intraoperative navigation is obtained. However, the limited data volume field of view introduces an additional difficulty when used with navigation. When placing the probe tip at the desired incision point, which is relatively far from the target point, the images with the anatomy disappear from the surgical navigation screen (Fig 1a). This prevents the surgeon from properly positioning and orienting the probe tip with respect to the images. This requires reverting to the old fluoroscopic verification method, which obviates the use of navigation.
Materials and Methods: We have developed a simple device, called the Field-Of-View Augmentation (FOVA) wand, to overcome the limited field of view typical of CT-like intraoperative imaging devices. The FOVA wand is designed to be an add-on to any commercial navigation system. It consists of two parts: a pointer and tracked slider mounted on it (Fig 1b). The pointer is a rigid 200mm cylinder with a handle. The slider is a rigid 150mm cylinder concentrically mounted on the pointer, with a dynamic reference frame rigidly mounted on it. The slider can translate on the pointer, thereby changing its location with respect to the pointer’s tip. The slider’s tip location with respect to the dynamic reference frame is calibrated, at the beginning of surgery as part of a regular tool registration by the navigation system.

The FOVA wand works as follows. Once the navigation system has been activated and the CT-like dataset of the region of interest has been acquired, the FOVA wand is defined. In its fully retracted position, the navigation field-of-view is at the pointer’s tip. Sliding the slider outwards (forwards) virtually displaces forward the pointer’s tip by the same amount. The virtual displacement of the pointer’s tip simulates the penetration of the pointer into the anatomy, thereby shifting the navigation field of view into the previously acquired CT-like dataset. This creates a situation in which the anatomical region of interest can be reached even though the physical tip of the device is outside the volumetric data set. This allows for accurate planning and positioning of the entry point and trajectory of the pointer outside the volume of the CT-like dataset.

A prototype FOVA wand was designed and built in house and added to a commercial navigation system (SureTrak® Medtronic) with the SIREMOBIL® Iso-C3D C-arm. A third generation saw bone femur (Sawbone®) was placed in a 30×30×50cm³ box. One face of the box was covered with penetrable foam the other was left open. A reference frame was attached to the box (Fig 1c). The model was CT scanned with the Iso-C3D C-arm and the image data was transferred to the navigation system. The dimensions of the box and the positioning of the saw bone created a volumetric data limitation for the navigation system as described earlier.

Five orthopedic surgeons tested the augmentation device by performing two in-vitro entry and positioning planning and targeting tasks: 1) reaching two 3mm disks in two distinct locations, and; 2) penetrating a duct drilled in the bone at a 25° angle to the femur shaft. Each task was timed for the planning and targeting. In addition, the FOVA device was used in-vivo in a clinical case in which a sacroiliac screw was taken out in a minimal invasive procedure using
intra-operative based navigation. The augmentation device was used since the volumetric data limitation was encountered.

**Results:** In-vitro experiment - all surgeons reported ease of understanding and use of FOVA device and its contribution to enhancing the navigation capabilities. The average time for the two disk targeting tasks was 1:19 mins and 1:01 mins for entry and positioning planning and 2:09 mins and 1:04 mins for actual targeting, respectively. The average times for the duct penetration task were 4:01 mins for planning and 1:43 mins for execution, respectively. Clinical case - the sacroiliac screw was reached directly and precisely with accurate angulation and successfully extracted in a minimal invasive procedure (Fig 1d).

**Discussion:** The FOVA is a simple, inexpensive, and easy to use add-on device for augmenting the field-of-view of navigation based on intraoperative CT-like images with a small data volume. It allows the simultaneous visualization and relative position adjustment of the point of entry and target. It is promising for obese patients and for pelvic procedures.

**References**


A Method Improving The Workflow And The Registration Robustness Of Ultrasound-guided Spine Surgery

PETERHANS M, TALIB H, GARCIA J, GONZÁLEZ BALLESTER MA

MEM Research Center, ISTB, University of Bern, Switzerland

matthias.peterhans@memcenter.unibe.ch

Introduction: In computer-assisted surgery, the registration between preoperative image volumes such as CT or MRI to the patient provides the surgeon with enhanced visualization and information about physically inaccessible regions. Ultrasound-based registration is a promising approach for achieving registration without direct physical access to the structures of interest. Instead of acquiring surface points of the object to be registered by a tracked pointer tool, a calibrated and navigated 2D ultrasound probe is used for the same purpose. This reduces invasiveness and allows for efficient acquisition of surface points.

The workflow for ultrasound-based registration includes probe calibration, acquisition of surface points by ultrasound imaging and the calculation of the registration transform. Probe calibration is a critical and time-consuming step that needs to be performed during surgery. Inaccuracies in the calibration affect the subsequent registration steps and might lead to erroneous registration outcomes. To solve this issue, self-calibrating ultrasound was proposed and shown to improve registration outcomes [1]. An additional problem in the US registration workflow is that the registration transform is calculated after image acquisition which leads to a waiting time for the surgeon and registration might fail if the acquired surface data does not provide sufficient information.

The method presented here aims to solve these issues by combining a fast frame-by-frame registration algorithm [2] with joint registration and calibration. Calibration is refined during the registration process and the frame-by-frame processing increases registration speed and provides real-time feedback indicating when sufficient information for registration is acquired.
**Materials and Methods:** Our joint calibration and registration method is divided into 2 steps: First an initial registration estimate is obtained in real-time using the Unscented Kalman Filter (UKF). Using a frame-by-frame formulation [2], a registration estimate is obtained within one iteration after the acquisition of an ultrasound frame. Based on this registration estimate, the user can decide to finish image acquisition when a sufficient alignment is obtained. In the second step, calibration and registration parameters are optimized using the Levenberg-Marquardt (LM) optimizer in a joint framework minimizing the distances between US surface points and the 3D model from CT. Our approach was compared to the initial self-calibration algorithm [1] which processes the entire dataset after image acquisition using a 3-step approach (first optimizing the registration transform, then registration and calibration and finally including image scaling parameters). Evaluation is performed on real ultrasound images of an L4 vertebra in a water bath. 36 tracked US images were acquired using a Philips Sonos 7500 US system in 2D mode. The imaged areas correspond to the features visible when scanning a patient from the back (spine, processes and transverse process). Phantom-based probe calibration [4] and pointer-based surface registration using ICP were used to establish a bronze standard for the registration and calibration parameters. Bone contours were segmented automatically by combining Otsu thresholding with a morphological opening and a thinning of the resulting contours [5]. Robustness and accuracy of the registration approach was evaluated by performing 100 experiments with initial parameter estimates which were randomly distributed within a range of ±10[deg], ±10[mm] for the registration parameters, ±5[deg], ±5[mm] for calibration parameters and ±10 percent around the true value for scaling parameters. This aims to represent the parameter variability obtained by a rough and fast initial registration and calibration.

**Results:** To evaluate the registration outcome, target registration errors (TRE) were calculated as the distance between bone surface points at the ground truth position and corresponding points at the position obtained by the registration algorithm. This corresponds to the errors to be expected in the surgical scenario. Figure c) shows the distribution of RMS errors over the 100 experiments: On the left, we see the TRE distributions for the initial registration estimates whereas in the following 3 histograms, the direct joint registration and calibration estimation using LM in a 3-step approach [1] is compared to the UKF frame-by-frame algorithm [2] and to our approach combining UKF and joint calibration and registration. If we define a successful registration as obtaining a TRE below 3mm, LM
succeeds in 44 cases whereas the combined UKF+LM approach leads to 61 successful registrations. The UKF frame-by-frame processing which is performed during image acquisition reduces the initial TRE in 97 out of 100 cases and hereby provides a reliable initialization for the second LM step. This has the effects of increasing the robustness of the combined approach vs. direct LM and reduces the average number of iterations in the LM algorithm from 44 to 29.

The error magnitude of 3mm RMS can be explained by uncertainties in the reference registration using a bronze standard obtained by phantom calibration and pointer-based registration and by errors introduced during image segmentation.

**Discussion:** The combined frame-by-frame UKF and joint registration and calibration method has shown to improve registration outcomes when starting from rough initial parameter estimates. Comparing with previously published studies [1,2] we obtain robust registration with larger ranges of initial estimates. This means that preoperative probe calibration and fast initial registration are sufficient to obtain reliable registration. Moreover, frame-by-frame processing provides real-time feedback to the surgeon, enabling them to determine when a sufficient amount of surface data is acquired. The joint calibration and registration approach allows correction of inaccurate probe calibration and
compensation for changes in speed of sound between the calibration phantom and the patient. Finally calculation time after image acquisition is reduced considerably, leading to a more practical US-based registration solution for computer assisted surgery.

References
Evidence-based Implant Design Using A Statistical Bone Model And Automated Implant Fitting

REYES M¹, BOUCHLER P¹, NOLTE LP¹, REIMERS N², LUTZ C², GONZÁLEZ BALLESTER MA¹

¹ MEM Research Center, ISTB, University of Bern, Switzerland
² Stryker Trauma GmbH, Germany

mauricio.reyes@memcenter.unibe.ch

Introduction: A key in the development of better bone implant design is to consider the natural shape variability found in a certain population. Being able to characterize such shape variability, and how this variability can be injected in the process of implant design has become an important issue within implant manufacturers. Ultimately, the aim is to design an implant that can be used across a population ensuring a good fit. While it is clear that no unique implant will fit as well in every bone, it is possible however to tailor the implant design to be as generic a possible. Thus, an important aspect of the design is to evaluate how well the current bone implant fitting is performing before any further analysis. To assess the quality of the fitting one can search for the distances errors produced when placing the implant on the bone surface. However, current rigid registration strategies as the classical Iterative Closest Point (ICP) do not consider aspects like collision detection between objects nor include more specific constraints which can come from anatomical or manufacturer specific criteria. In this paper, a modified Iterative Closest Point (ICP) technique, tailored to the specific task of bone implant fitting was developed. Collision constraint was incorporated to ensure that no points in the implant mesh model fall inside the bone model. In addition, fitting guidelines provided by the implant manufacturer were included as fitting constraints, this in order to find plausible implant fitting. These specific constraints favors fittings of the implant that are collinear as much as possible with the bone main axis, and do not go above the bone plateau.

The constrained ICP algorithm is based on the optimization of the following functional: \( \text{argmin} \sum W_i |e_i| \), where \( W_i \) and \( e_i \) are the corresponding weight and distance error for point \( i \) in the implant mesh model, respectively.
The weights $W_i$ are computed as a linear combination of constraint-specific weights for collision, implant-bone co-linearity and tibia plateau. Furthermore, in order to avoid biases due to the number of points inside the volume, an analytical expression was found to counter this. To favour bone-implant fittings that are collinear as possible with the bone main axis, the angle between these two axis was computed and used as constraint weight. For this, the main axis of the implant model and the bone are required. This is performed through a Oriented-Bounding-Box (OBB) decomposition of both shapes. Furthermore, for the implant model, only the lower region was used in order to improve the alignment between the bone shaft and the implant. A 4-level OBB decomposition of the implant was then used. A final constraint comes from the fact that the implant cannot be positioned further up the bone plateau; this constraint was then implemented as penalties to points going up this plane.

The method was tested on two statistical models of tibia bones, generated from segmented CT scans of left human tibia. For the construction of the statistical models, dense-field correspondences for every bone and a reference one was found using a non-rigid registration algorithm, which was applied to the masked CT images in order to recover only the tibia structure. The Active Shape Model (ASM) method was then used to statistically model the shape variability of bones. A first model describes a Caucasian population of 43 bones and a second one, describes Asiatic population of 47 bones. The statistical shape models were used to generate new valid instances, yielding two new datasets of 67 bones for each population and using the first five modes of variation, corresponding to 94% of the total shape variability. For each new dataset 30 instances were generated using 6 different values or weights for each of the first 5 modes of variation alone, and 37 were generated as combination of the first 3 modes between four different values. These combinations were generated assuring that the generated instances are within the 94% of the Gaussian distribution of the model. For each instance the constrained bone fitting procedure was performed and the distance error at each point on the implant shape was computed. An overall mean distance and standard deviation was then computed to measure quantitatively the quality of the fitting.

Results: For the Asian population a mean distance error of 1.77mm and standard deviation of 0.836mm was found. For the Caucasian population the mean distance error and standard deviation was found of 1.57mm, and 0.625mm, respectively. Figure 1 shows the mean errors found for the caucasian population mapped as colors in the implant surface (left), and one sample case of the resulting fitting on a bone (right).
Discussion: A tailored fitting algorithm for bone implant fitting was developed and tested on a statistical model of left human tibia for two different populations. Although the method was presented for tibia bones, the method can be easily adapted to consider other anatomical constraints. The use of statistical models provides a valuable tool to evaluate the impact of shape variability on a given implant design.
Calibration Of Preoperative 2D X-ray Radiographs And Its Potential Applications In Computer-assisted Total Hip Replacement

SCHUMANN S¹, TANNAST M², NOLTE LP¹, ZHENG GI

1 MEM Research Center, ISTB, University of Bern, Switzerland
2 Department Of Orthopaedic Surgery, Inselspital, University Of Bern, Switzerland

Guoyan.Zheng@MEMcenter.unibe.ch

Introduction: In the past ten years, a variety of computer-assisted surgery technologies have been introduced for total hip replacement (THA). Despite the different approaches, orthopedic surgeons routinely still acquire 2D X-ray radiographs for preoperative diagnostic and templating purposes. Such images provide detailed information about the underlying anatomic structures with high resolution. Since X-ray as a two-dimensional imaging technique cannot provide depth information, we present a procedure of calibrating X-rays within the usual clinical environment and discuss subsequent 3D reconstruction of the proximal femur for potential applications in computer-assisted THA.

Materials and Methods: For hip joint related applications in orthopedics, two different views (anterior-posterior and axial) are demanded. The calibration of the X-ray radiographs is performed using a two-plane method as reported in [1] [2] [3]. Therefore, for each X-ray radiograph, two parallel calibration plates are brought into the line-of-sight of the X-ray source (see Fig. 1). The plates are made out of a radiolucent material, containing several radio-opaque markers. Since the acquirement procedure of the X-ray radiographs for THA is well standardized, the calibration plates are fixed to a main frame, which can be easily mounted to the table, where the patient is lying for taking the X-ray. The calibration is based on the establishment of the correspondence between a set of 3D points with known coordinates and on the other hand on their associated 2D points detected from the projection images. The 3D coordinates of those points are acquired by direct pointer digitization. Their corresponding positions in the
projection images are obtained by applying a cross-correlation based template matching.

Results: The accuracy evaluation of the calibration approach is split up into investigation of the forward projection and the backward projection accuracy. For this reason we manufactured a phantom with 4 radio-opaque markers made out of lead, visible in both X-ray radiographs. The 3D coordinates of these fiducial markers are determined by digitization using an NDI Optotrak 3020 camera. In a next step, two X-ray radiographs of the phantom are acquired. Based on these X-ray radiographs, the 2D coordinates of projected fiducial markers can be easily detected as the ground truth. To evaluate the projection accuracy, the 3D coordinates of the fiducial markers are projected onto the X-ray radiographs according to the equations given by [3], resulting in 2D projection positions. These coordinates are then compared to the previous determined 2D coordinates. According to the described method, the projection can be determined with a RMS of 11.27 ± 5.58 pixels. Based on previous studies, we derived the conversion from pixels in mm to be 1 pixel equal to 0.12 mm. Therefore the projected markers can be determined by an average error of 1.35 mm. The backprojection-accuracy is determined, by backprojecting the determined 2D coordinates of the fiducial markers. This results in a line-of-sight for each fiducial marker in each X-ray radiograph. The unique 3D position of each marker can be now determined by minimizing the distance between respective line-of-sights of both X-ray radiographs. The 3D position of each
marker can be determined with an average RMS of 1.21 ± 0.2 mm.

**Discussion:** In this work, we proposed a technology to accurately calibrate pre-operative X-ray radiograph and verified its accuracy using a phantom. Calibrating X-ray radiograph allows for 3D measurement and computation. One possible application of our newly developed technology is to provide 3D surface models for computer-assisted THA applications without the requirement of acquisition of CT data. For this purpose, we have developed a program which allows for interactive definition of anatomical landmarks and bone contours in a pre-operative step. Next, the approach developed by Zheng et al. [4] is used to construct a 3D surface model of the proximal femur. Intra-operatively, this model is then transformed to the patient reference coordinate system by registering a sparse set of points, which are digitized directly from the bone surface, to the reconstructed surface model.

We are currently working on the verification of the 3D reconstruction accuracy. The method developed by Zheng et al. [4] was previously verified with calibrated C-arm images. Average reconstruction error of 1.2 mm was reported when two calibrated C-arm images were used. In this work, we plan to evaluate the 3D reconstruction accuracy using 20 dry femur bones. The surface model acquired by a high precision laser scanner (T-SCAN laser scanner, Steinbichler, Germany) will be taken as the ground truth. The reconstructed 3D model will be directly compared to its associated ground truth to get a surface-to-surface distance, which will be taken as the reconstruction error. More results are expected by the time of CAOS symposium.

**References**


Determination Of Bone Healing By “intelligent” External And Internal Fixator Systems

SEIDE K¹, MAegerlein S¹, SCHULZ AP², GERLACH U¹, JUergens C¹, FASchingBAUER M¹

¹ Dept Trauma & Orthopaedics, Bg Trauma Hospital Hamburg, Germany
² Dept Trauma & Orthopaedics, University Hospital Luebeck, Germany

maegerlein@apschulz.de

Introduction: The period that orthopaedic surgeons judge a fracture or osteotomy as being „not stable“, and therefore e.g. limit the weight bearing, are determined by historical experience in a large population accompanied by serial radiographs. We developed a motorized hexapod external fixator, initially for the bloodless accurate fracture reduction. Our aim was it then to determine the rate of fracture healing after reduction. To achieve this, it was necessary to implement measurement and/or control capabilities to the hexapod. After first clinical use of such a system, we went one step further. By adding electronic measurement capabilities to an osteosynthesis plate, we were able to constantly monitor bony healing. Development and first clinical use of the systems is described in detail.

Materials and Methods: An external fixator based on the parallel robot kinetics (hexapod) was developed. With this, exactly computable bone movements could be performed. Especially, a slow and careful fracture reduction was possible. A prototype incorporating 6 electromotors was build and used for computer controlled fracture reduction in 5 patients. By incorporation of 6 force sensors in line with the linear actuators of the hexapod it was then possible to measure fixator loads in 6 degrees-of-freedom (i.e., axial and shear forces as well as bending and torsion moments). A study was performed in 9 patients. In the next step, a load measurement system was also applied to an internal fixator (incorporating a locked screw-plate interface, see figure). A microcontroller based telemetry unit (size 12mm x 12mm) with a transmission range of 8cm was incorporated in the osteosynthesis plate. After animal and cadaver testing, this was applied in 5 Patients treated for a femoral non union. Local ethical committee approval was granted for this study.
**Results:** Monitoring of the bone healing as well as an optimal control the load during physiotherapy and weight bearing could be measured. The data acquired showed a good correlation between the measurements and radiographs taken during the healing process. There were no major technical problems or adverse effects for the patients. All implants worked during their clinical application. Average load increases were measured with a zero setting at an axial weight bearing of 10 kg. The highest increase was measured with 500%, interestingly this was when the patient was asked to straighten his knee with maximal force in a supine position. Other stress, including physiotherapy under full weight bearing with torsional component, showed less increase. Although the serial measurements during fracture healing showed marked differences during fracture healing, we are at the moment not able to give the exact time of fracture healing, the amount of datasets is still too low for a reliable determination.

**Discussion:** By combining measurement and motor control, it will be possible in the near future to mutate external fixators to fully functional robot-systems. Additional to fracture reduction, the increment in weight bearing can be determined by the system and automatically adapt its mechanical properties to fulfill load requirements of the emerging callus. Intelligent internal fixators will give the surgeon valuable information regarding the healing process. Serial radiographs will not be required. In our view, fracture reduction robots and „intelligent“ external fixators as well as microelectronic instrumented and load measuring internal fixators can be a routine tools of the orthopedic trauma surgeon in the future.
Haptics And Virtual Reality For Knee Arthroscopy Training: Does Vibrotactile Feedback Help?

TENZER Y, DAVIES BL, RODRIGUEZ Y BAENA FM

Department Of Mechanical Engineering, Imperial College, London, UK

f.rodriguez@imperial.ac.uk

Introduction: A training simulator with a custom developed haptic device named Ortho-Force was developed at Imperial College for knee arthroscopy training. It is capable of providing limited force bandwidth, which has shown to be suitable for the reproduction of “moderately high collisions”. However, for hard contact simulations (e.g. surgical probe on bone) it has obtained only limited success despite the highly geared motors in each joint [1].

Materials and Methods: For this study, a special add-on device for the OrthoForce System was developed. It consists of a voice coil, special hardware to drive the coil by amplifying signals generated by a PC sound card, and a software application, used to modulate custom oscillatory signals (sinusoidal wave plus decaying exponential) transmitted through a standard 3.5mm output jack. The system is capable of modulating very high frequency signals, up to 40Khz.

During knee arthroscopy, the hooked probe comes into contact with three main tissues: cortical bone, bearing cartilage and the meniscus. As such, each of these tissues should be modelled. The simplest way of describing a decaying vibration signal mathematically is via a sinusoid, modulated by a decaying exponential. In order to find the constants of the vibration model for the tissues, an experiment was performed on three cadaver knee bones in Charing Cross Hospital, London. An experienced surgeon touched the tissues with a standard arthroscopy hooked probe, with an accelerometer (303A PCB, Buffalo, New York) magnetically attached to the handle. The vibration signal was first recorded using a custom written Labview (National Instruments, Inc.) program, then analysed in Matlab (MathWorks, Inc.). The signal was low-pass filtered, then its Fourier spectrum analysed to find the dominant frequency component of the vibration. It was found that there is no significant difference
in the frequency of the contact vibrations between the meniscus and articular cartilage, while the vibration frequency resulting from probe-bone interactions is much higher.

A special system setup was then implemented for the experiments, which aimed to identify whether vibrotactile feedback could be used to improve a) the haptic realism of the device and b) the “hardness sensation” in probe-bone collisions. Only the proximal extremity of the tibia bone model, which is clearly divided by the “intercondylar eminence” into two parts, (i.e. the medial and lateral sides), was presented to the user. In the first experiment, vibrotactile feedback with a signal frequency similar to that of the bone, i.e. 420Hz, was added to collisions experienced on the right side (as it appeared on screen) of the tibia bone surface, while the left side only included the force feedback generated by the virtual environment. The users were asked to tap repeatedly onto the virtual bone surface, paying particular attention to the sensation, felt through the hand, when the probe first came into contact with the bone. During the experiment, users had to decide if the left side felt different to the right side and, if so, which one felt more realistic. In the second experiment, a different setup was proposed; vibrotactile feedback was provided to both surfaces; the left one with a vibration frequency of 380Hz, similar to that of cartilage, and the right one with a vibration of 420Hz, to mimic that of bone. In this case, the users were asked to decide whether there was a difference in haptic feedback between the right and the left surface and, if so which one felt harder. During all the experiments, users were asked to put headphones, which were playing music, and ear defenders to ensure that any noise generated by the voice coil would not bias the experiment in any way. A randomised group of people (n = 14, with 9 engineers and 5 surgeons) was recruited for the study. All members of the group were exposed to the same experimental setup and protocol. Before the start of the experiment, each one received a general explanation about the device and several minutes on the haptic simulator to familiarise themselves with the setup, working envelope of the system and hand-eye coordination. After this first familiarisation step, each group member was exposed to the first experiment and, after a two minutes brake, to the second experiment. None of the users witnessed the performance of any of the other members of the group and the final numbers were only revealed once all volunteers had completed the experiment.

Results: The limited set of experiments performed to date suggests that the vibrotactile extension developed for the experiments was moderately successful in improving some aspect of the haptic interaction. Positive results from the first
Experiment (Figure 1a) show that the inclusion of vibrations feedback could be noticed and that it induced most users to experience a collision as being harder, without the need for a corresponding increase in force bandwidth. However, the conflicting results obtained in the second experiment (Figure 1b) suggest that the value of these vibrations may be limited, although current hardware and software shortcomings may be responsible for these results.

Discussion: In conclusion, vibrotactile feedback for medical applications is still in its infancy, but may hold some potential as an effective means to improve the haptic realism of a surgical trainer. The current results only offer limited evidence to support this hypothesis, but the results outlined were deemed sufficiently promising to warrant a further investigation. Additional hardware modifications, better software scenarios, and a more comprehensive statistical study are among the planned activities for future work.

References
Two Camera Augmented Mobile C-arm - System Setup And First Experiments

TRAUB J1, HEINING SM2, EULER E2, NAVAB N1

1 Computer Assisted Medical Procedures (camp), Tum, Munich, Germany  
2 Trauma Surgery Department, Klinikum Innenstadt, Lmu Munich, Germany  

traub@in.tum.de

Introduction: Mobile C-arm systems are established in everyday routines in orthopedic and trauma surgery. The trend toward minimally invasive applications increases the use of fluoroscopic images within surgery and thus the radiation dose. One approach towards intraoperative guidance using mobile C-arm systems was the augmentation of intraoperative acquired image data onto an optical camera that is rigidly attached to the gantry [1]. A single optical video camera was rigidly attached to the gantry such that the optical center and X-ray source coincide using a special arrangement with a double mirror construction. This enabled a real time video and X-ray image overlay that was registered by construction. No registration of the patient was required in their approach. As an extension of this system, we developed one that is capable of depth control and requires only one additional X-ray image and a second video camera rigidly attached to the C-arm. After a one time calibration of the newly attached video camera we are able to show the instrument tip in a lateral X-ray view. The feasibility of the system has been validated trough cadaver studies where we successfully identified all six pedicle screws placed using the procedure. The accuracy of the placement was validated using a postoperative CT.

Materials and Methods: The system consists of an Iso3D C-arm (Siemens Medical, Erlangen, Germany) with two attached Flea video color cameras (Point Grey Research Inc., Vancouver, BC, Canada). The first camera is attached as proposed earlier by using a double mirror construction with X-ray transparent mirrors [1]. The second camera is attached orthogonal to the gantry such that its view is aligned with the X-ray image after a 90 degrees orbital rotation of the C-arm (cf. figure 1 (a)). Furthermore, the system includes a standard PC
with a framegrabber card to access the analog images of the C-arm. A custom developed visualization and navigation software is used. For both cameras the calibration process can be divided into two consecutive steps [2]. In the first step the cameras are physically attached such that the optical center and axis virtually coincide with the X-ray imaging system at all time for the gantry mounted camera and at particular C-arm positions for the orthogonal mounted camera. The second step is to compute the homographies to align the video images with the X-ray images. For both video cameras the distortion is computed using the Matlab camera calibration toolbox and the images are undistorted using Intel OpenCV library. The use of flat panel displays or standard distortion correction methods is recommended. The workflow of the procedure contains the positioning of the C-arm in the down-the-beam position, rotation around 90 degrees to take the lateral X-ray image, rotate back to the down-the-beam position, start the intervention using the image overlay system by defining the entry point, aligning the instrument tip and aligning the instrument in the down-the-beam axis. The second camera is capable of the control of the insertion depth, enabled by tracking the instrument in the orthogonal mounted camera. Since it is registered with the lateral taken X-ray, the tool can be projected into this X-ray view and the insertion depth can be controlled visually.

**Results:** First the feasibility of the system was tested on a spine phantom. We used a tracked awl, a pedicle probe and a T-handle to place pedicle screws. Using a lateral control X-ray image we could visually verify the accuracy of the depth navigation. In a cadaver experiment we placed eight pedicle screws (Universal SpineSystem USS, Synthes, Umkirch) with a diameter of 6.2 mm in four vertebrae of the thoracic and lumbar spine (Th12-L3). The surgical procedure was carried out in three steps using a pedicle awl to open the cortical bone, a pedicle probe to penetrate the pedicle, and a T-handle for screw implantation. For the guided procedure both augmented views, lateral and AP, were visualized simultaneously on two monitors. After aligning the optical axis of the C-arm imaging system with the desired direction of the pedicle screws, the acquisition of only two X-ray images was required for each pedicle screw. This is a considerable reduction of radiation compared to standard fluoro based procedure. The accuracy of the pedicle screw placement was verified by a postinterventional CT. Five pedicle screws were classified by an independent medical expert to be in central screw position without perforation. The other three screws were classified to have a small lateral screw perforation within thread diameter. For none of the eight pedicle screws a medial perforation in direction of the spinal canal occurred.
Discussion: We have extended a real-time video augmented X-ray to a multi-view imaging system. The previously proposed single camera augmentation system has proven to be efficient for trauma surgery and orthopedic applications where 3D did not matter. The second camera enables applications that are only possible at the moment using permanent fluoroscopic imaging or C-arm with 3D reconstruction capabilities and external tracking systems, both resulting in considerable increase of the radiation dose. Our newly developed system proved that it is possible to perform these procedures with the use of only two X-ray images in our laboratory setup and the assumption that the object does not move after the X-ray acquisition. If the object moves, another pair of X-rays has to be acquired. First cadaver experiments demonstrated that the new system can be easily integrated into the clinical workflow while reducing the radiation dose compared to other methods. The observed accuracy during the experiments is clinically acceptable. Further work will compare quantified results with CT based and C-arm based standard navigation techniques and incorporates methods to track motion of the anatomy in order to indicate that a pair of new X-ray images is required. The invention and implementation of a system for real-time augmentation of orthogonal X-ray views of a surgery, opens the way for development of new C-arms with integrated 3D navigation capabilities with no further need for online calibration.
Acknowledgement:
This project was partially supported by Siemens Medical Solutions.

References
Instrument Tracking In Endoscope Images Using Binary ID Based Markers: Initial Results

THORANAGHATTE R, NOLTE LP, ZHENG G

MEM Research Center, ISTB, University of Bern, Switzerland
ramesh@memcenter.unibe.ch

Introduction: Dexterity of the surgeon is compromised during endoscopic surgeries and hence tracking the instruments and providing navigation proves to compensate it. Instrument tracking has been tried using mechanical, optical, magnetic and ultrasound based methods [1]. But they are costly and either require to maintain line of sight or good acoustic/magnetic environment which can be demanding on the normal workflow of surgical procedures. Tracking instruments in endoscopic images has been tried previously [2, 3, 4] but the methods are not robust, less accurate and cannot function in realtime. In this paper we propose a method to track the instruments using binary Id based markers [5]. These markers are squares of size less than 10 mm and can be easily attached to the shaft of the endoscopic instruments which is usually 10 mm in diameter. Figure 1(a) shows endoscope image with id based markers attached to the shaft of endoscopic instrument. Results show that the method is robust, accurate for the purpose, functions in realtime and costeffective.

Materials and Methods: Tracking ID based markers
We are using ARToolkitPlus to track multiple predefined markers and obtain their 6DOF (position and orientation) information. We had previously tried ARToolKit with good results [6], but tracking multiple markers with it was cumbersome since it uses correlation based marker identification method. ARToolkitPlus has an advantage of tracking markers with an embedded binary code implicitly and is faster. We have modified it to track multiple markers and incorporated precise calibration and undistortion routines to suit endoscope setup.
Calibration and undistortion of endoscope images
Images of a black and white checker-board pattern, with squares of size 2.5 mm, are used for calibration with Matlab based calibration toolbox [7]. The
reprojection error was 0.5-1 pixel. Projection matrix, radial and tangential distortion coefficients are obtained simultaneously. The distortion coefficients are used to undistort the video stream in real time.

Evaluation
Evaluation was done for positional accuracy. Three grids with multiple markers of size 10 mm, 7.5 mm and 5 mm were created using PaintShopPro software which provides micrometer level control (Figure 1b). The markers center were separated with a distance twice their size. The same distance was calculated by ARToolKitPlus, after undistortion. The difference was expressed as error. The grids were kept at 1.5 cm from the endoscope tip and then incremented by 0.5 cm upto 5 cm and error was assessed (Figure 1c).

**Results:** All the central five markers were detected up to 5 cm distance except in the 5 mm grid which failed after 4 cm. This is due to reduction of markers size in the image. There was no false positive identification of the markers. Frame rate of 10-12 per second was achieved. Figure 1(d) shows the error for various sized markers. The error drastically increases with size at 2 cm distance. This can be attributed to inaccurate undistortion. In our case it seems to be due to over correction which we have to deal with in our future work. Error is consistently around 1 mm with all marker sizes from 2.5 to 5 cm distance from endoscope tip.

**Discussion:** In this paper we presented a cost-effective, robust, fast and accurate method to track endoscopic instruments. This is better than the current existing
methods as it doesn’t require any special equipment or modification in surgical workflow to track the instruments. The markers can be printed out on a sterile adhesive paper and attached to the instruments or can be printed directly on the instruments during their manufacturing process. Two to three markers are enough to track an instrument but having more will increase accuracy and robustness of the method. In our future work we want to include this tracking method in our navigation application for endoscopic spinal surgeries.

References
5. Artoolkitplus, open source optical tracking software.
   URL: http://studierstube.icg.tu-graz.ac.at/handheld_ar/artoolkitplus.php
Shape Reconstruction From Endoscopic Images

Wu C¹, Narasimhan SG¹, Jaramaz B²

¹ Robotics Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
² Institute Of Computer Assisted Surgery, The Western Pennsylvania Hospital, Pittsburgh, Pennsylvania, USA

branko@icaos.org

Introduction: Endoscopy is an important visualization tool in minimally invasive orthopedic surgery. During surgery an endoscope consisting of a camera and one or more light sources is inserted through a small incision into the body and the acquired images are analyzed. Due to the small field of view, only a small part of the bone and its occluding contour are visible in any single image, making a perception of bone shape from such images difficult. We present a novel technique to reconstruct the surface of the bone by applying shape-from-shading to a sequence of endoscopic images, with partial boundary in each image. We demonstrate the accuracy of our technique using simulations and experiments with artificial bones.

Endoscopy is attracting increasing attention for its potential role in minimally invasive computer aided surgery. Since the field of view of the endoscope is small and the bone is usually a few millimeters away, only a small part of the bone can be observed at a time. As a result, it can be difficult even for a skilled surgeon to infer bone shape from a single endoscopic image. Better visualization can be achieved by overlaying endoscopic images with 3D surfaces obtained from CT scans [1]. However, this still requires us to solve a complex registration problem between CT and endoscopic images during surgery. Thus, there is an immediate need for explicit computer reconstruction of bone shapes from endoscopic images.

Since bone surfaces have few identifiable features, surface shading is the primary cue for shape. Shape-from-shading has been used in computer vision and biological perception, [4, 2]. But all these works assume the light source and camera center are co-located. Due to the small field of view, only a small part
of the shape of interest can be reconstructed from a single image. By capturing image sequences as the endoscope is moved, it is possible to cover a larger part of the shape that can be more easily perceived [3, 5]. However, that is difficult to achieve for relatively textureless bone or cartilage surfaces. Therefore, neither shape-from-shading nor shape-from-motion can individually solve the problem of bone reconstruction from endoscopic images. In this work we combine the strengths of both approaches to develop a global shape-from-shading approach using multiple partial views.

**Materials and Methods:** First, for a single image, we formulate shape-from-shading under a near-point light source and perspective projection, given only a partial object boundary, when the source and camera are not optically co-located. Because the endoscope is tracked during image acquisition we can then transform the sequence of reconstructed shapes from a local view to a global coordinate frame. Initially, due to the errors in tracking, calibration and reconstruction, the individual shapes are not fully aligned. We use iterative closest point (ICP) algorithm to match them further. The shape-from-shading is then restarted for all images simultaneously, using boundary constraints in world coordinates in each iteration. This process of growing shape locally and updating constraints globally is iterated until convergence.

**Results:** The orthopedic endoscope has a single camera and one or more point light sources equipped at the tip of the scope. For this work, we used the Stryker 344-71 arthroscope Vista (70 degree, 4mm), an oblique endoscope with two point light sources. The algorithm is first tested on a series of synthetic examples and then on the shape reconstruction of a synthetic spine model (147mm x 60mm x 60mm) from 18 images. Figure shows the key procedure steps (a-d) and demonstrates the accuracy of our technique (e) by comparing the reconstructed shape with the ground truth shape obtained using a laser range scanner. For comparison, we choose only the points that are on the surface of the spine. The maximum, minimum, mean and RMS errors are 3.1mm, 0.0mm, 1.16mm and 1.5mm respectively. With global constraints, our algorithm converges quickly, though not real-time (around 5 minutes for 18 images in Matlab, P4 2.4G CPU).

**Discussion:** Shape-from-shading and shape-from-motion are both successfully used in many vision applications, but both have difficulty when applied to orthopedic endoscopy due to relatively featureless surfaces and partial occluding boundaries in a small field of view. In this work, we combine the strengths of both approaches: we formulate a shape-from-shading for single
image under near point lighting and perspective projection, and develop a global shape-from-shading algorithm using multiple partial views. A shape of a larger bone area can then be reconstructed, providing useful visualization for surgical navigation in a minimally invasive procedure. We believe that our techniques can significantly enhance the capabilities of endoscopy in minimally invasive orthopaedic surgery. There are several unsolved problems such as automatic boundary detection, obtaining good initial guesses, recovering high frequency details in shape, dealing with image noise due to blood and tissues.

Acknowledgements
This work is supported in parts by an NSF ITR Grant #0325920, an NSF CAREER Award #IIS-0643628, an NSF Award #CCF-0541307 and an ONR Award #N00014-05-1-0188.

References
Introduction: CT-free navigation system has gradually become popular in TKR (Total Knee Replacement). However, it still requires mechanical jigs to guide vibrating saw for bone resection. The knee surgical robot in this paper is developed to fulfill both the functions of intraoperative surgical planning and bone resection. No mechanical jigs are needed. The surgical robot has similar planning function as the current navigation system. After surgical planning, the bone resection function of the robot can be performed in a simpler way because software jig is used to replace the mechanical one. Since bone consists of hard cortical and soft cancellous bone and cartilage, unpredictable and sudden rising of the cutter forces may arise from contacting harder tissue during bone resection. This will result in inaccurate bone preparation if the cutter deviates from the path; or cause serious danger to the patients or medical staffs if the cutter is broken. Thus the robot is under a cooperative force controller to overcome the above issues. The result from a cadaver test shows the developed robot is of high potential of providing an effective solution for a CT and Jig-free assisted robot for TKR.

Materials and Methods: A cooperative force control is used to fulfill the planning and cutting function of the robot. The cooperative force control law is shown as in Fig. 1. Two layers of force control are used to represent the cooperation between the robot and the surgeon. In the surgical planning mode, a surgeon can easily move the tool tip to measure the anatomical feature of the knee joint so that the cutting boundary can be generated. In bone resection mode, the federate of the cutter in bone resection is determined by the surgeon input the force command $F_h$. At the same time, the cutting force $F_B$ is measured and is also used to modify the federate of the cutter. The surgeon can also...
feel the cutting force and allow the surgeon to sense where the cutter is or he should stop pushing the cutter further more. The federate is implemented by an inner loop adaptive fuzzy controller. The position controller can cope with the variant friction forces arising from the mis-alignment during the assembly of the robot links so that exact positioning can be accomplished. There are advantages to close the control loop by a surgeon. Because the robot is not intelligent as a surgeon, a surgeon can make judgment to slow down the cutting speed for certain safety critical region to avoid damaging the nerves and blood vessels. However, a surgeon may be responded too slowly for sudden rising cutting force so that cutter deviation or break may happen. The cooperative force control can combine both strengths of surgeon’s intelligence and robot’s response speed and achieve better bone resection outcome.

Results: TKR Experiment on a cadaver was performed by using the developed robot as shown in Fig. 2. The feed rate of the cutter was able to be adjusted rapidly to response the sudden rising of the cutting force. It can be observed from Fig. 3 that the feed rate was able to slow down to response the rising cutting force. In Fig. 4, the combination of human’s force input and the measured cutting force simultaneously affect the feed rate of the cutter.

Discussion: In this paper, the developed TKR assisted robot demonstrates the advantages of using a cooperative force control to achieve robotic navigation and bone resection. The CT-free and Jig-free feature of the robot provides an cost-effective solution for TKR.
References


Introduction: Short leg radiographs remain the standard radiographs available in many UK hospitals. The aim of this study was to see if these radiographs are reliable when assessing the post-operative alignment of total knee arthroplasty in comparison to a Hip-Knee-Ankle (long leg) radiograph.

Materials and Methods: Twenty consecutive 6 week post-operative long leg radiographs, taken with a standardised protocol, and a short leg radiograph derived from the same digital image were each examined on two separate occasions by two observers. These radiographs were from both navigated and standard instrumentation total knee arthroplasties. On the long leg radiograph the anatomical and mechanical axes were calculated and on the short leg radiograph the anatomical and surrogate mechanical axes were calculated. In clinical practice when looking at short leg radiographs, the tendency is to use the tibial component alignment as a surrogate for the mechanical axis of the tibia as we know that we aim to prepare the tibia perpendicular to the femoro-tibial mechanical axis. Our surrogate mechanical axis was therefore taken from the position of the tibial component in relation to the axis of the tibia. These data were used to investigate intra- and inter-observer error. A single observer also collected the same measurements on an additional 30 radiographs (total of 50) to further investigate any patterns of error between measurements derived from long leg and short leg radiographs of the same knee.

Results: On the long leg radiographs, intra-observer agreement was good for both anatomical and mechanical axes for both observers (Intraclass Correlation Coefficients [ICC] of greater than 0.95). The anatomical axis on short leg radiographs was also good (ICC = 0.92 and 0.76). Intra-observer agreement
for the short leg radiograph derived mechanical axis was not as consistent (ICC = 0.73 and 0.56). Inter-observer variability was good for long leg radiographs for both anatomical (ICC = 0.89) and mechanical (ICC = 0.95) axes. On short leg radiographs, however, agreement was not as good, in particular for the mechanical axis (ICC = 0.51), but also the anatomical (ICC = 0.73). Taking the long leg radiograph values as the most accurate, there was a difference in the magnitude of errors seen on short leg radiographs dependant on the knee alignment. Varus aligned knees (n=24) had an average error of 1.2° (0° to 3°) for the anatomical axis and 1.6° (0° to 4°) for the mechanical axis. Perfectly aligned knees (n=8) had an average error of 3.0° (1° to 6°) for the anatomical axis and 2.9° (1° to 5°) for the mechanical axis. Valgus aligned knees (n=18) had an average error of 3.4° (0° to 8°) for the anatomical axis and 5.8° (2° to 11°) for the mechanical axis. Using a Mann-Whitney test the magnitude of error was greater for valgus knees for both anatomical (p<0.0001) and mechanical (p<0.00001) axes when compared to varus knees. Interestingly all except one knee measured on the long leg radiograph as valgus aligned appeared to be in varus on the short leg radiograph. Figure 1 gives the measured mechanical axis for both long leg and short leg radiographs for all 50 knees showing the aforementioned differences.

**Discussion:** In conclusion, short leg radiographs are inadequate to make any comment on leg alignment in total knee arthroplasty. This is most pronounced
in a valgus aligned knee. This is of particular importance in computer-assisted surgery which has proven to be highly accurate in coronal total knee arthroplasty alignment. Despite the fact the long leg radiographs can sometimes be considered inaccurate with respect to CT, short leg radiographs cannot in any circumstances be used for alignment assessment.
The Application Of Computer Assisted Surgery In Revision Total Knee Arthroplasty

Bae DK, Song SJ, Noh JH, Chang WS, Cho HJ

Department Of Orthopedic Surgery, School Of Medicine, Kyung Hee University

tesstore@live.co.kr

Introduction: The purpose of current study is to analyze the accuracy of mechanical axis and implant positions postoperatively and to evaluate the efficacy of computer assisted navigation surgery for bone cutting and ligament balancing in revision TKA.

Materials and Methods: twenty-six revision total knee arthroplasties were performed by a single surgeon with use of computer assisted surgery from July 2004 to August 2007. There were twenty-four female patients and two male patients. At the revision, the mean age was 64.6 years. The mean interval from index arthroplasty was 10.5 years. The cause of revision included twenty polyethylene wears and six loosenings. We used augmentations in twenty-two patients and we used structural allograft in sixteen patients who had severe bone defects. Two observers measured mechanical axis, position of implants, and level of joint lines. The joint line A was defined as the shortest vertical distance between distal end of femoral component and proximal tip of fibula. The joint line B was defined as the shortest vertical distance between medial femoral epicondyle and distal end of femoral component.

Operative technique: Modular Deupy P.F.C.-SIGMA (Johnson & Johnson, Warsaw, Indiana, USA) knee system was used all patients. Cemented stems were used for tibial and femoral components. Revision TKA was performed using the CT-free version 1.5.1 of BrainLAB’s (Munich-Heimstetten, Germany) VectorVision-system. For the registration, surface points were acquired with the old prosthesis in place. The femoral cutting block was orientated in real-time visualization and adjusted in a way that only a minimal bone resection...
was necessary to achieve a normal knee joint line. The tibial cutting block was orientated in real-time visualization and adjusted in a way that only a minimal bone resection was necessary to achieve a good bony covering of the tibia tray. After femoral and tibial preparation, the flexion gap and extension gap were checked with spacer block. The ligament balancing was performed with controlling the stability of the knee in extension and flexion by navigation system.

**Results:** By observer I, the mechanical axis improved from varus $10.21 \pm 8.18^\circ$ to valgus $0.56 \pm 1.87^\circ$, and mean $\alpha, \beta, \gamma, \delta$ angle were $95.61 \pm 1.62^\circ$, $90.29 \pm 1.36^\circ$, $3.55 \pm 2.35^\circ$, $87.11 \pm 1.44^\circ$ respectively. Also, the joint line A was elevated from $15.43 \pm 4.24\text{mm}$ to $18.66 \pm 4.70\text{mm}$ and the joint line B was elevated from $23.51 \pm 4.62\text{mm}$ to $26.41 \pm 3.14\text{mm}$. By observer II, the mechanical axis improved from varus $10.17 \pm 8.10^\circ$ to valgus $0.58 \pm 1.88^\circ$, and mean $\alpha, \beta, \gamma, \delta$ angle were $95.67 \pm 1.66^\circ$, $90.15 \pm 1.17^\circ$, $3.64 \pm 2.14^\circ$, $87.37 \pm 1.50^\circ$ respectively. Also, the joint line A was elevated from $15.54 \pm 4.26\text{mm}$ to $18.69 \pm 4.56\text{mm}$ and the joint line B was elevated from $23.27 \pm 4.84\text{mm}$ to $26.23 \pm 3.20\text{mm}$. There were positive correlations between the measured angles by observer I and observer II significantly ($p<0.05$).

**Discussion:** Accurate bone cutting and verification in each step were possible with real time information provided by the CAS TKR. Mechanical axis, component positions, joint line could be checked and adjusted with feedback of navigation system. Information about flexion and extension gap and ligament balance could be verified during revision surgery.
Computer Assisted Total Knee Arthroplasty On Valgus Knees: Subgroup Identification

Basanagoudar P, Deakin AH, Vijay A, Picard F

Department Of Orthopaedics, Golden Jubilee National Hospital, Clydebank, UK

angela.deakin@gjnh.scot.nhs.uk

Computer assisted total knee arthroplasty (TKA) enables the measurement of the dynamics of the knee both before and after the implant of the prosthesis. Much time has been spent looking at the outcomes of navigated TKA however less time has been invested on understanding how the data collected pre-operatively can inform the surgeon and help the surgical decision making process. The aim of this work was to use navigation as a tool to quantify and classify preoperatively valgus knees.

Between August 2006 and September 2007 a group of 51 patients who demonstrated intra-operative initial neutral or valgus aligned knees underwent navigated TKA using the Columbus knee prosthesis and the Orthopilot® navigation system (B.Braun, Aesculap). Demographic data were recorded, along with the preoperative radiograph appearance and clinical assessment of alignment. During the surgery the approach used and the knee mechanical femorotibial (MFT) angle through the range of flexion were recorded. The knees were then categorised as either “True” valgus or “False” valgus based on whether the MFT angle at 30°, 60° and 90° flexion was still valgus (True) or had gone into varus (False).

Five patients were excluded from the study group as they had incomplete data in knee flexion. Of the remaining 46 patients, 28 were True valgus and 18 were False valgus. For the two groups demographic data were compared. Male to female ratio was 9:19 for the True valgus and 4:14 for the False valgus. The mean age of the True group was 70 years (range 52-85 years) and the False was 69 years (range 53-84 years). For BMI the True group had mean of 31 (range 20-40) and False of 33 (range 26-42). Twenty-five of the 28 True valgus knees
showed preoperative evidence of clinical genu valgum deformity and radiologic
evidence of predominantly lateral compartment osteoarthritis. Five patients
had ipsilateral hip replacements in the past and five had rheumatoid arthritis.
Seventeen were operated by lateral parapatellar approach. Eighteen required
ilio-tibial band release with additional lateral collateral ligament release in five
knees. Six true valgus knees did not require any soft tissue release. Five patients
required lateral retinacular release to achieve thumb free patellar tracking. The
median operating time for the True valgus group was 80 mins. Ten of the 18
false valgus knees showed evidence of clinical varus deformity and radiological
evidence of predominantly medial compartment osteoarthritis. Only one patient
had an ipsilateral hip replacement in the past and one had rheumatoid arthritis.
All 18 knees underwent TKA by medial parapatellar approach, requiring no
additional soft tissue release in 17 knees and a moderate release in one knee.
The median operating time for the False valgus group was 60 mins.

Valgus deformity in TKA poses a major challenge on terms of soft tissue
balancing, surgical approaches and bone resection height. Navigated TKA
measures, in real time, the alignment and soft tissue behaviour such as range
of motion and arc of motion. This makes it a useful tool for valgus deformity
assessment. True valgus knees had more significant deformities clinically and
radiologically, longer surgical time and more incidence of soft tissue release
when compared to the False valgus knees. False valgus knees behaved like
varus knees clinically, radiologically and intra-operatively and should therefore
be treated as such when making surgical choices.
Effect Of Knee Prosthesis Positioning On Tibio-femoral And Patello Femoral Joint Kinematics - In-vitro Analysis Of Cruciate-retaining And Posterior-stabilized Design

Belvedere C¹, Leardini A¹, Ensini A², Feliciangeli A², Bianchi L², Catani F², Giannini S²

¹ Movement Analysis Laboratory, Istituti Ortopedici Rizzoli, Bologna, Italy
² Department Of Orthopedic Surgery, Istituti Ortopedici Rizzoli, Bologna, Italy

belvedere@ior.it

Introduction: The comprehension of the mechanics of total knee arthroplasty (TKA) and its influence on joint mobility requires accurate analysis not only of the tibio-femoral (TFJ), but also of the patello-femoral joint (PFJ) kinematics, particularly in relation to prosthesis component positioning on the femur, tibia and patella, in case of resurfacing.

Till now, only a few studies in-vivo and in-vitro have addressed dimensional motion at the prosthetic knee reporting together TFJ and PFJ motion, and prosthesis component positions [1, 2]. Computer-aided surgery has recently introduced knee surgical navigation systems in TKA. These are able to monitor, with a good level of accuracy, all six degrees of freedom of TFJ kinematics during all phases of TKA and to improve prosthesis component positioning. Recently, also PFJ motion has been analysed thoroughly [3].

The aim of this study was to assess in-vitro the performance of two different prosthesis designs for TKA, both with and without patellar resurfacing, on both TFJ and PFJ kinematics by considering also component positioning on anatomical planes. A surgical knee navigation system, suitably adapted to this study aim, was used as measurement system.
Materials and Methods: Sixteen TKAs were performed on as many fresh frozen legs from cadavers. Cruciate-retaining (CR) and posterior-stabilized (PS) TKA (Scorpio®, Stryker Orthopaedics, Mahwah, NJ-USA) were implanted on eight specimens per prosthesis design, both with and without domed-patellar resurfacing. All TKAs were performed by using a standard navigation system (Stryker®, Kalamazoo, MI-USA) also used as measurement system. Particularly, the relative standard tools were used to track femur and tibia; an adapted software plus an additional trackers were also used to track the patella. Both TFJ and PFJ were analyzed using recommended [4, 5] or recently proposed [2] joint and anatomical conventions. TFJ and PFJ motion were analyzed during passive flexion/extension cycles in a 0°-140° flexion arc, both at the intact and replaced knees under condition of 100 N vertically applied at the quadriceps. Correlation coefficients (R) and relative p-values (P) were calculated among a number of parameters which describe joint kinematics and prosthesis component positions. For the former, the three translations and three rotations of the TFJ and PFJ after TKA, both with and without patellar resurfacing, were sample at 90° flexion, i.e. after the patella is fully engaged into the sulcus, for a total of 24 parameters. Femoral and patellar, in case of resurfacing, prosthetic component positions and orientations in the three anatomical planes were also measured, for a total of additional 12 parameters. Both kinematics and positions were taken with relevant anatomical reference frames preliminarily defined at the intact specimen.

Results: In CR-TKA, independently from patellar resurfacing, significant correlations were observed between femoral component orientation in transverse plane and TFJ internal/external rotation (R=0.81; P=0.02), and between femoral component orientation in sagittal plane and knee translation along tibial medial-lateral anatomical axis (R=-0.82; P=0.03). These correlations are absent in PS-TKA. After patellar resurfacing, independently from TKA design, significant correlations were observed between positioning along patellar antero-posterior axis, i.e. patellar thickness, and PFJ flexion (R=-0.77; P=0.02) and tilt (R=-0.73; P=0.03). In the figure, final femoral component position from a well representative specimen on the femoral frontal, transverse and sagittal anatomical plane. The trans-epicondylar axis and the Whiteside’s line are also over-imposed together with the patellar motion, represented as the patellar frame origin translations on the same femoral anatomical planes.

Discussion: The results show how all three component positioning affects both TFJ and PFJ kinematics. In PS, a general lower correlation is observed between femoral component position and TJF and PFJ kinematics. In case
of resurfacing, an incorrect restoration of the original patellar thickness alters further PFJ kinematics. This can result in-vivo in anterior knee pain, patellar subluxation and, ultimately, TKA failure.

Careful component positioning and intra-operative joint kinematics are important and enabled by current knee navigation systems.

References


Perioperative Fractures Of The Femur and Tibia In Computer Assisted Total Knee Arthroplasty: Identifying Risk Factors And Correlation With Rigid Body Trajectory

BHATTACHARYYA M, GERBER B

Department Of Orthopedic, University Hospital Lewisham, London, UK

mayukhbhattacharyya@hotmail.com

Introduction: Total knee arthroplasty (TKA) is commonly performed for relief of pain secondary to degenerative joint disease. Recently computer assisted knee replacement surgery offers excellent outcomes in terms of biomechanics. It was reported that failure caused by malalignment, and consequently wear and osteolysis may be avoided with the use of computer-assisted procedure.

There are also reports of adverse events such as periprosthetic fracture following TKA, which may be secondary to additional rigid body fixation [1] and other numerous etiologic factors [2,3]. This study presents three patients who developed periprosthetic fracture above the femoral component in two cases and below the tibial component in one case. Clinical and radiographic examinations, as well as surgical follow-up, are presented. We analysed the autopsy findings to review the fracture of the distal femur occurring after total knee arthroplasty in order to identify risk factors related to rigid body fixation site on the distal femur. We prospectively reviewed the effect of rigid body fixation site on the femur and tibia on the subsequent occurrence of a periprosthetic fracture of the distal aspect of the femur and proximal aspect of tibia after computer assisted primary total knee arthroplasty in such patients.

Materials and Methods: Three periprosthetic fractures occurred between 2003 and 2007 among 316 navigated total knee arthroplasties performed during this period. The circumstances of these fractures were noted in comparison with other prosthetic implants specifically to address the influence of rigid body
fixation site as a stress riser. Two fractures of the distal femur and one fracture of the proximal tibia occurred in patients who had had a total knee arthroplasty during the same time period. Mean patient age at surgery was 72 years (range 69-77). In addition to demographic data, we assess risk factors such as bone demineralization related to general condition, inflammatory arthritis or corticosteroid therapy, trochlear notch prior to the trochlear cut, bone resorption under the femoral implant, history of previous knee surgery, abnormal stress on the distal femur due to hip disease, periprosthetic osteolysis without loosening related to polyethylene debris or metallosis, loosening, type of prosthesis, loss of bone stock because of the femoral implant, life of prosthesis and rigid body fixation sites.

Results: Rigid body trajectories were analysed in 316 knees in our series. During an average follow-up period of 4.1 years, only two supracondylar femoral fractures and one proximal tibial fracture occurred. In all cases fracture initiated below the screw hole.

All the patients were osteoporotic either due to aging or to a long duration corticosteroid treatment. All happened after minor trauma (fall from height). The fractures were diaphyseal above the prosthesis, which was well fixed. Periprosthetic fractures may occur in specific circumstances, probably excessive resorption bone in osteoporosis (psoriatic arthritis with steroid use). The periprosthetic fracture was observed in one patient who had prior surgery of the distal femur (fracture of the distal femur, in one patients with significant loss of bone stock and had a history of neurological impairment and frequent falls. The trochlear notch was not present in any of these cases. The rigid body fixation site was not appear to be sufficient to be the only cause of fracture as fracture line was not initiated from the fixation site as found during the autopsy.

Discussion: This study shows that fracture of the distal femur and proximal tibia occurs in certain preferential circumstances. The rigid body fixation site may not be responsible for initiating such a fracture. Nevertheless, it may an element frequently associated with such a fracture.

Mortality associated with such a periprosthetic femoral fractures is often complex, and Jung et al reported that up 11% of patients died within one year following surgical treatment of a periprosthetic fracture and after a periprosthetic femoral fracture risk of death was significantly higher [4]. In our study case, only one patient died with 30 days of her index operation.
Although the notching on the anterior femoral cortex greater than 3 mm with sharp corners located directly at the proximal end of the prosthesis produced the highest stress concentrations and may lead to a significant risk of periprosthetic fracture [3], we found no evidence of notching in those cases with supracondylar periprosthetic fracture. During primary surgery the navigation data recorded 0 valgus & 0 mm inside the cortex. 

Anterior femoral notching during arthroplasty has been implicated as a contributing risk factor for femoral fracture [3]. However, one clinical study demonstrated no difference in knees managed with or without notching of the anterior distal aspect of the femur with respect to the occurrence of a supracondylar fracture [5].

In this case series we also analyzed the prevalence and orientation of rigid body trajectories on a review of the lateral radiographs by independent radiologist blinded to the clinical results of three consecutive total knee replacements with periprosthetic fracture. We could not establish the relationship between rigid body trajectory and the prevalence of supracondylar femoral fracture and tibial disphyseal fracture.

References

In total knee arthroplasty (TKA), the incorrect restoration of the original joint line (JL), i.e. the approximate proximo-distal level over the leg of the articulating surfaces in full knee extension, has been shown to result in instability, anterior knee pain, limited range of motion, and joint stiffness. Figgie et al. showed that 8 mm JL elevation can be statistically correlated with functional knee score, tibio-femoral range of motion, patello-femoral pain, and rates of revision and manipulation surgeries. Calculation of the JL height is usually performed by measurements on latero-lateral X-ray pictures, comparing the different levels at pre- and post-operative conditions, as measured with an height up to a common point such as the fibular head, the medial epicondylar, or the tibial tuberosity. Computer assisted surgery, which has been recently introduced in TKA surgery for improving implantation alignment of the femoral and tibial components, now provides a suitable and accurate instrument for such measurements. In the present study, variation of femoral and tibial JL height before and after replacement was measured intra-operatively with an accurate surgical navigation system.

The present prospective study involved 71 (44 female, 27 male) consecutive primary TKAs (Scorpio Posterior Stabilized System - Stryker, New Jersey, USA) performed by two senior surgeons among the authors, operating into two different centres (Istituti Ortopedici Rizzoli - A 35 operations, and Spital Oberengandin - B 36 operations). Twelve patients were lost at follow-up. The final population was of 59 patients (37 female, 22 male). Calculation of JL
height variations required the following intra-operative procedures: a- digitisation with the navigation pointer of the original surfaces on the medial and lateral compartments of the tibial plateau at the arthritic knee; b- measure of the position of the proximal tibial osteotomy; c- measure of the position of the base-plate of the final tibial metal back component. To these latter height, the thickness of the polyethylene insert was added, this being the distance between the deepest point of the polyethylene, which is equal in the two compartments, and the tibial component’s metal back edge, as provided by the company. The clinical evaluation of the patients was made with a minimum 1 year follow-up using the International Knee Society (IKS) score. The mean follow-up was 20.6±3.9 months (range 12-31 months).

A 2.2±2.4 mm mean elevation (max. 8 mm uplift, min. 3 mm downlift) of the JL between preoperative and postoperative conditions was observed. No correlation was found between JL height variation and postoperative IKS score or range of motion. The mean postoperative IKS ‘function’, IKS ‘knee’, and range of motion was respectively 87.6±16.4 (min.40, max. 100), 91.7±7.9 (min.63, max 100), and 120.2°±13.9° (min 75°, max 145°). The distribution of the JL height variation has shown in the Figure.

Using a simple technique implemented in a standard navigation system, for the first time JL height was measured intraoperatively before and after TKA. The mean 2.2±2.4 mm elevation demonstrated a good restoration of the JL height after TKA. No statistically significant correlations between this figure and clinical results at a short follow-up were found. This might be accounted for the small variation of JL height, with most of the patients having experienced this within a -5±1 mm interval, and with 2 patients only experiencing 8 mm (Figure).
Electromagnetic Navigation In Total Knee Arthroplasty

CHEUNG KW, CHIU KH, TSO CY

Department Of Orthopaedics And Traumatology, Prince Of Wales Hospital, The Chinese University Of Hong Kong, Hong Kong, China

kwcheung@ort.cuhk.edu.hk

Introduction: Malalignment of more than three degrees in coronal plane was associated with poor outcome. Most of the alignment occurred in the tibial coronal plane alignment. Computer assisted surgery (CAS) in total knee arthroplasty (TKA) aimed to minimize malalignment. CAS can give a real-time feedback to the surgeon and achieve a better alignment. Electromagnetic navigation in total knee arthroplasty was developed in recent years. It aimed at high accuracy and easy signal detection. However, there was limited result published.

Materials and Methods: From August, 2006 to December, 2007, 45 patients had TKA performed with electromagnetic navigation (EM CAS-TKA) with Medtronic electromagnetic navigation system. The results were compared with 45 matched patients who had TKA performed with conventional technique. The post-operative limb alignments were compared. Conventionally, more than three degrees were defined as outliers. More than two degrees of malalignment was defined as outlier in this study aiming at detecting outlier in a more stringent way.

Results: There was no significant difference in the age, sex distribution, pre-operative range of motion and pre-operative deformity between the two groups. EM-CAS TKA group has significantly less deviation from neutral in the tibial coronal plane ($p = 0.012$) than conventional group. Conventional group has significantly more deviation from neutral alignment than EM-CAS TKA in the femoral sagittal plane ($p = 0.007$) plane. There were no significant difference in tibial sagittal, femoral coronal and overall coronal plane alignment between the two groups ($p = 0.369, 0.203$ and $0.051$ respectively). There were significantly more outliers (>2° malalignment) in tibial coronal plane ($p = 0.004$) and femoral
sagittal plane (p = 0.02) in conventional group than EM-CAS TKA group. There was no significant difference in the outliers in femoral coronal plane, tibial sagittal plane and overall coronal plane alignment (p = 0.833, 0.523 and 0.523 respectively). The tourniquet time was significantly longer in EM-CAS TKA group (average, 95.2 minutes) than conventional group (average 84.9 minutes (p = 0.006). There was no pin tract complication nor infection in the electromagnetic navigation group.

**Discussion:** Electromagnetic navigation had improved the tibial coronal plane and femoral sagittal plane alignment in total knee arthroplasty with less outlier. Better alignment may improve the survival of the prosthesis. Electromagnetic navigation has the potential application in minimally invasive total knee arthroplasty. However, electromagnetic navigation is more time consuming than conventional technique.

**References**
The Use Of Navigation To Investigate The Relationships Between Tourniquet Time, Pre-operative Deformity And Surgical Experience In The Varus Knee

Davies H¹, Voon SH², Sampath SAC²

¹ Department Of Orthopaedics, Addenbrooke’s Hospital, Cambridge, UK
² Bluespot Knee Clinic, Classic Fylde Coast Hospital, Blackpool, UK

howarddavies@doctors.org.uk

Introduction: Total knee arthroplasty (TKA) in patients with a severe pre-operative varus deformity can be technically demanding and time consuming. Unless the prosthesis is implanted to within 3 degrees of the neutral axis it is predisposed to aseptic loosening and consequently early revision. The advent of image free navigation has improved the accuracy of prosthetic implantation in patients with severe deformity and has provided a tool for reproducible outcome measurement. Our aim was to use navigation to demonstrate that severe varus deformities could be corrected reproducibly with TKA. We also wanted to explore the effect that both degree of pre-operative deformity and the surgeons experience with the implant had on the length of surgery.

Materials and Methods: 172 e.motion uncemented rotating platform total knee replacements (B Braun, Tuttingen, Germany) were implanted into 160 patients with varus deformities using the OrthoPilot® version 4.2 image free navigation system (B Braun) with soft tissue balancing. The tourniquet time (TT) was recorded automatically by the tourniquet machine which was operated by the anaesthetic staff independently of the surgical team. The post-operative mechanical alignment was recorded by the OrthoPilot® software.

Results: The mean tourniquet time (TT) for all procedures was 62.1 minutes (range 39-122). The mean pre-operative mechanical axis was 6.6 degrees varus (range 0 to 35; SD 4.87). The mean post-operative alignment was 0.48 degrees varus from the neutral axis (range -2.0-3.0; SD 0.92) p<0.001 (t test). Using simple regression analysis we have demonstrated relationships between TT and
the independent variables: degree of pre-operative varus (p<0.001); number of previous e.motion knees implanted (p<0.001); and Body Mass index (p=0.013). Tourniquet times are increased as the pre-operative deformity increases and as the BMI becomes larger and are decreased as the surgeon implants more knees and therefore becomes more experienced.

Multivariate analysis has demonstrated a linear relationship between the tourniquet time and each of the variables in the form of a mathematical equation that can be used to predict operating time for the procedure:

\[ TT = 49.5 + \text{PreOp Varus} + 0.6(\text{BMI}) - 0.1(\text{total previous}) \]

TT is measured in minutes.
Preoperative varus is measured in degrees from the neutral axis.
Total previous is the total number of e.motion TKA's implanted by the surgeon for any pre-operative deformity.

**Discussion:** Image free navigation is a suitable tool to reproducibly correct severe varus deformity to a neutral alignment during TKA. The length of surgery is related to the size of the deformity and the BMI of the patient. With experience of both the implants and the software a surgeon can reduce his operative times significantly. Although a learning curve exists with the OrthoPilot® we found this was linear with no plateau, suggesting that the surgeon continues to improve even after several hundred cases.

A linear relationship exists between the independent variables (pre-op varus, BMI, previous experience) that when expressed in a mathematical form allows us to predict tourniquet time for this procedure. This has socioeconomic implications as it may allow us to plan operating lists with greater accuracy, therefore reducing redundancy in the operating room and reducing waste of resources. As the equation accounts for previous experience, the TT can also be factored for trainees who will require more time for a procedure than an experienced surgeon.
PiGalileo Robotic Navigation in Total Knee Arthroplasty

GOLDBERG T

Texas Orthopedics, Austin, TX, USA
tgoldberg@texasorthopedics.com

Introduction: Obtaining a neutral mechanical axis alignment during TKA is critical in the long term durability and implant survival. Numerous references cite the improved accuracy obtained with utilization of Computer-Assisted (CAS) techniques. The present prospective study evaluates a single surgeon's experience with CAS and the addition of a passive robot for preparation of the femur.

Materials and Methods: 415 patients undergoing primary TKA were evaluated between January, 2006 and January 2008. All patients underwent similar surgical protocol for surgical implantation, anesthesia, and post-operative rehabilitation. Pre-operative information obtained included diagnosis, clinical diagnosis, and knee scores. Intraoperative data collected included kinematic assessment of the knee pre- and post-arthroplasty as well as tourniquet time and final mechanical axis. Standard post-operative data was collected, with special attention to complications.

Results: The passive robot functioned each time and was not navigation was not abandoned in any case. There were cases of notching the femur (0.5%). There were 5 reoperations; however, only 1 of these was revision of the components secondary to infection. There was no symptomatic PE or death. One popliteal artery injured occurred from intimal stretch requiring stent placement. Fourteen manipulations were performed for post-operative arthrofibrosis (3.3%). Average tourniquet time was 41 minutes (1-101min). There were 2 mechanical axis outliers for a 99.5% mechanical axis alignment accuracy rate.

Discussion: While TKA surgery consistently yields excellent clinical results, long term durability continues to depend upon the placement and fixation of components as well as balance of the knee. Navigation with the addition of Passive Robotics can improve surgeon accuracy during TKA.
**Introduction:** To get a balanced knee is desirable after total knee replacement (TKR) or unicompartmental knee replacement (UKR). Navigation systems are able to measure very accurately the movement of bones, and consequently the knee laxity, which is a movement of the tibia under the femur. These systems might help measuring the knee laxity during the implantation of a TKR or a UKR.

**Materials and Methods:** 20 patients operated on for TKR (13 cases) or UKR (7 cases) because of primary varus osteoarthritis have been analyzed. Pre-operative examination involved varus and valgus stress X-rays at 0 and 90° of knee flexion. The intra-operative medial and lateral laxity was measured with the navigation system at the beginning of the procedure and after prosthetic implantation. Attention was paid to get a balanced knee according to our definition: between 2 and 4° of medial laxity in extension and in flexion, between 3 and 5° of lateral laxity in extension and in flexion. Varus and valgus stress X-rays were repeated after 6 weeks. X-ray and navigated measurements before and after TKR were compared with a paired Wilcoxon test at a 0.05 level of significance.

**Results:** The mean pre-operative medial laxity in extension was 2.3° (SD 2.3°). The mean pre-operative lateral laxity in extension was 5.6° (SD 5.1°). The mean pre-operative medial laxity in flexion was 2.2° (SD 1.9°). The mean pre-operative lateral laxity in flexion was 6.7° (SD 6.0°).

The mean intra-operative medial laxity in extension at the beginning of the procedure was 3.6° (SD 1.7°). The mean intra-operative lateral laxity in extension at the beginning of the procedure was 3.0° (SD 1.3°). The mean intra-operative medial laxity in flexion at the beginning of the procedure was 1.9° (SD 2.6°). The mean intra-operative lateral laxity in flexion at the beginning of
the procedure was 3.5° (SD 2.7°). The mean intra-operative medial laxity in extension after implantation was 2.1° (SD 0.9°). The mean intra-operative lateral laxity in extension after implantation was 1.9° (SD 1.1°). The mean intra-operative medial laxity in flexion after implantation was 1.9° (SD 2.5°). The mean intra-operative lateral laxity in flexion after implantation was 3.0° (SD 2.8°). The mean post-operative medial laxity in extension was 2.4° (SD 1.1°). The mean post-operative lateral laxity in extension was 2.0° (SD 1.7°). The mean post-operative medial laxity in flexion was 4.4° (SD 3.3°). The mean post-operative lateral laxity in flexion was 4.7° (SD 3.2°).

All cases had an acceptable post-operative leg axis on both navigated and X-ray measurements. 17/20 cases were considered balanced at the end of the procedure. 7/20 cases were measured balanced on the post-operative stress X-rays.

There was a significant difference between navigated and radiographic measurements for the pre-operative medial laxity in extension (mean = 1.4° - p = 0.005), the pre-operative lateral laxity in extension (mean = 2.6° - p = 0.01), the pre-operative lateral laxity in flexion (mean = 3.3° - p = 0.005). There was no significant difference between navigated and radiographic measurements for the pre-operative medial laxity in flexion (mean = 0.3° - p = 0.63).

There was a significant difference between navigated and radiographic measurements for the post-operative medial laxity in flexion (mean = 2.5° - p = 0.004). There was no significant difference between navigated and radiographic measurements for the post-operative medial laxity in extension (mean = 0.3° - p = 0.30), the post-operative lateral laxity in extension (mean = 0.2° - p = 0.76), the post-operative lateral laxity in flexion (mean = 1.7° - p = 0.06).

These differences were less than 2 degrees in most of the cases, and then considered as clinically irrelevant.

**Discussion:** The navigation system used allowed measuring the medial and lateral laxity before and after TKR. This measurement was significantly different from the radiographic measurement by stress X-rays for pre-operative laxity, but not statistically different from the radiographic measurement by stress X-rays for post-operative laxity. The differences were mostly considered as clinically irrelevant. The navigated measurement of the knee laxity can be considered as accurate. The navigated measurement is valuable information for balancing the knee during TKR. The reproducibility of this balancing might be improved due to a more objective assessment.

The navigation system used allows measuring accurately and objectively the knee laxity during TKR.
How To Acquire L-M Stability With Navigated TKA In Extension And Flexion: The Past And The Future

KANESAKI K, YAMANAKA K, NAGATA K

1 Nagata Orthopedic Hospital, Omuta, Japan
2 Kurume University, Kurume, Japan

kintaro_60_3583@yahoo.co.jp

Introduction: Osteo-arthritis is a prevalent disease among the world. In Japan, over 90 percent of OA knees have varus deformity. The “varus deformity” here, means that the mechanical axis of the lower leg is in varus position to the femoral mechanical axis in standing situation. Conventionally, the evaluation of this statue was limited to use the long film X-ray in supine or standing position. This evaluation will be based on immovable images and static situation that it cannot appreciate the durability of TKA. Nowadays, the technology of kinematic computer-assisted navigation system is advanced in the bony alignment check capability, however, not in the ligament balance check capability. OrthoPilot navigated TKA software manufactured by Aesculap (Germany, Tutulingen) has the technology of ligament balance check capability, of which intra-operative registration is not so troublesome. It is a kinematic navigation system, and does not require pre nor intra-operative examination such as CT examination or image-intensifier. TKA is performed using OrthoPilot since October 2003 at our institute, and we have adopted MIS-TKA from 2005. In navigated TKA, there is a phase to check the position of the lower extremity. The display shows the angle, which is so-called “varus deformity” or “valgus deformity”. We check this angle at two different points of time. The first point of time is after arthrotomy, only with bony registration, pre-meniecetomy or pre-osteophtectomy. The second point of time is post-implantation when closing the wound. In both positions, we push the heel providing some power forward the axis of lower extremity, to imitate weight-bearing gait. Without any pushing power, there is a risk of “varus deformity” being underestimated and loosened knee after implantation being over looked. We have evaluated the angles in full-extended position, 45 and 90 degrees of flexion, as well as full flexion. The discrepancy of the former 4 points and the latter 4 points demonstrates the
stability of TKA, and it leads to the long durability of TKA. We had over 100 cases of navigated TKA so far. Recently, we have started to check alignments in every degree. Only nine cases had those 8 points of angles checked so far, which we would like to discuss today, as well as anticipate the durability of the navigated TKA.

**Materials and Methods:** Nine cases were all female. Seven cases were OA knee and two cases were RA. The two cases of RA were with severe OA change, one was with 13 degrees of varus deformity in full extension, and the other was with 8 degrees. Average age at the time of the operation was 74.5 years old (range from 64 to 85). We will discuss the L-M instability angle in every point, full extension angle and full flexion angle.

**Results:** The average full extension angle was -4.3 degrees (range from -16 to 1) and full flexion angle was 148.4 degrees (range from 143 to 152) at the first check point (at pre-meniscectomy or pre-osteophtectomy). The average varus deformity angle was -10.8 degrees (range from -20 to -4) in full extension. The average varus deformity was -8 degrees (range from -17 to -3) at the 45 degrees flexion point, and it was -8 degrees (range from -14 to 0) at the 90 degrees flexion point. In full flexion, it was -3.6 degrees (range from -9 to 2). The average angle of the maximum discrepancy was 7.4 degrees (range from 1 to 13), which means that the average L-M instability is 7.4 degrees pre-operatively. At the point of post-implantation full extension angle was -1.5 degrees (range from -5 to 1) and full flexion angle was 148.4 degrees (range from 136 to 154). The average varus deformity angle was -0.78 degrees (range from -3 to 1) in full extension. At the 45 degrees flexion point, it was -0.87 degrees (range from -3 to 3), and at the 90 degrees flexion point it was -1.22 degrees (range from -4 to 3). Finally in the full flexion, it was -0.44 degrees (range from -3 to 5). The average angle of the maximum discrepancy was 2.78 degrees (range from 1 to 5). This angle indicates that the average L-M instability is 2.78 degrees post-operatively. The number of cases are too small to discuss any statistical suggestions, however, there is a tendency to reduce the L-M instability angle in every checking point.

**Discussion:** Basically, good position of bilateral components is perpendicular to each mechanical axis. And needless to say, by perfect ligament balance, the long durability will be achieved. Without navigation system, until today, especially without OrthoPilot, we could only evaluate the static analysis of the stability with the lower extremity X-ray. On top of that, it was only in full-extended position. However, OrthoPilot provides us both the evaluation
of ligament balance and the dynamic stability of the lower extremity totally, during surgery. With OrthoPilot, we can set the priority between the ligament balance and the axis of the component setting intra-operatively. Usually at our institute, TKA is performed using OrthoPilot placing the priority in the ligament balance. Consequently our results showed that there is a tendency to reduce the discrepancy of L-M instability. The angle in full extension is also reduced. Long durability of TKA with OrthoPilot can be expected.

TKA was performed using the kinematic navigation system, OrthoPilot, and the L-M instability at several points were evaluated. The instability between pre-meniscectomy and post-implantation was compared. The results showed that there is a tendency to reduce the discrepancy of M-L instability. However, we only have a few cases to make any statistical suggestions so far.
Influence Of Weight Simulation On Navigated Lower Limb Axis Measurements: Cadaver Testings

Kendoff D1, Citak M2, Hankemeier S3, Board T3, Gardner M4, Kretteck C2, Hufner T2

1 Hospital For Special Surgery, New York, USA
2 Trauma Department, Hannover Medical School, Germany
3 Department Of Orthopaedics And Trauma, University Of Manchester, UK
   And Wrightington Hospital, Wigan, UK
4 Trauma Department, Harbourview Medical Center, Seattle, USA

kendoffd@hss.edu

Introduction: Successful outcomes following high tibial osteotomy (HTO) require precise realignment of the mechanical axis of the lower extremity. Traditional methods used to assess the mechanical axis intraoperatively are often cumbersome and inaccurate. Navigation allows for a precise determination of the mechanical leg axis intraoperatively, however the inability to accurately assess the weight bearing axis intraoperatively may account for inappropriate degrees of correction with the osteotomy. We tested the hypothesis that axial loading of the limb affects alignment during an HTO procedure.

Materials and Methods: A custom mechanical load apparatus (MLA) was developed to simulate weight bearing conditions intraoperatively. Fixation to the trunk was achieved by supraacetabular pins and an external fixation device, which allowed the pelvis to be rigidly fixed relative to the MLA while axial load was applied to the foot. Ten fresh cadavers were used for testing. The baseline mechanical axis was determined by a navigation system. HTO was then performed, and varying degrees of valgus correction were obtained and stabilized. For each correction, one quarter, one half, or full body weight was applied axially to the foot, and the axis deviation was measured. Subsequently the MCL was partially and completely released to determine the effect of ligament incompetence. For all tests, the load was disengaged and reapplied three times each by two separate observers, and the measured values of the six trials were averaged to obtain a mechanical axis deviation value for that
specimen trial. Significance was considered p < 0.05, and all statistical analyses were performed using a commercial statistical software package (SPSS v. 11.0, SPSS Inc., Chicago, IL).

**Results:** Preliminary results in our laboratory indicated that stable fixation of the MLA to the pelvis was feasible. Successful application of load up to 94 kg was achieved without deformation of the limb or the system. Baseline knee alignment in the 10 specimens ranged from 3.5° of varus to 2° of valgus. In the first set of tests, application of axial load to the intact limbs did not result in any axis deviation above 1°. At ¼ body weight load, the average was 0.3° (SD, 0.2°); at ½ body weight, axis deviation from base line was 0.4° (SD, 0.2°); and at full body weight, average deviation was 0.5° (SD, 0.2°). Intra- and inter-observer reliability was not determined, but the variability was within 1° for all trials, which is within the resolution of a navigation system in general.

The second set of tests was performed with varying degrees of correction following osteotomy, and application of incremental loads. All trials resulted in significant increases in mechanical axis deviation (p < 0.01). Following 2.5° of correction, the average axis deviation from baseline increased from 0.9 to 1.6° as load increased from ¼ body weight to full body weight. The number of specimens that changed at least 1° increased from 6 to 10 (Table 1). With 5° of correction, the axis deviation change ranged from 1.0° to 1.8° as the load increased to full body weight. With 7.5° of correction, deviation increased from 1.2° to 1.9°. With full body weight load applied, the axis in all
10 specimens changed by at least $1.2^\circ$, regardless of the amount of osteotomy correction (Table 1). The third testing series involved partial and complete of the MCL. With partial release of the ligament, although the axis deviation tended to be greater compared to without release, no significant changes occurred in any group (Table 2). However, when the MCL was released completely, a significant increase in the axis deviation occurred in 5 of the 9 testing groups. At all magnitudes of osteotomy correction, application of a full body weight load resulted in a significant increase in mechanical axis change (Table 2).

**Discussion:** In conclusion, we suggest that intraoperatively the influence of weight bearing must be considered by the surgeon, especially if a partial or complete release of the MCL is carried out. Significant increases in valgization occur with increasing load application to the lower limb. When assessing intraoperative correction of alignment, this change in the axis should be accounted for to avoid under or overcorrecting. The exact nature of the clinical sequelae of these axis shifts requires further investigation.
Introduction: Navigation has been shown to provide better positioning of knee prostheses. Large meta-analysis have demonstrated an up to 20% increase in well positioned implant vs conventional surgery. However, issues remained with time, invasiveness and cost. To further improve accuracy as well as time and cost, an intelligent robotic instrument system has been developed completely integrated into an available navigation system1. The goal of the bone-mounted robot, named Praxiteles, is to precisely position a surgical bone-cutting guide in the appropriate planes surrounding the knee, so that the surgeon can perform the planar cuts manually using the guide. The robot architecture is comprised of 2 motorized degrees of freedom (DoF) whose axes of rotation are arranged in parallel and are precisely aligned to the implant cutting planes with a 2 DoF adjustment mechanism. Aim of this study is to present first clinical results and complications and pitfalls of this system.

Materials and Methods: Since January 2008 the Praxiteles System is used together with a navigational system manufactured by PRAXIM (La Tronche/France). The Praxiteles is mounted on the femur by two pins using the so called ARCHE mounting system. The pins are the same that are used for the infrared trackers. The navigation system uses infrared-tracking and bone-morphing software. We report very early results in a prospective case series. In all cases we will use a ROCC Total Knee (Biomet, Berlin, Germany). The approach is anterior, an minimal invasive approach will not be used in this study. The first step of the procedure is equal to the standard navigated knee arthroplasty with marker pins in femur and tibia, determination of axes and, in case of the Praxim system, bone morphing. Then the tibial cut is performed using navigation. The robot is then mounted on the femur and after the final planning, the five cuts for the femoral component are performed. According to
the manufacturer, the system can be used with all available TKA models. The implant is then positioned, we use cemented, cement free and hybrid fixation according to the patients specific needs.

The aftertreatment is standardised regarding ROM, CPM, physiotherapy and weight bearing. For 2 weeks partial weight bearing with 20 kg and 60° maximal flexion, then 2 weeks 90° will be enforced. Focus is on the intra-operative complications including technical, learning curve and procedure duration. Early clinical follow up at 12 weeks includes radiographic examination, axes, the combined Insall knee score and patient satisfaction scores. The follow up examination will be by an independent examiner, local ethical committee approval has been attained and there is external study monitoring.

Discussion: The Praxiteles is only available since 2008, first clinical use took place in December 2007. We realize that the scientific results gained by Summer 2008 can only be limited, nevertheless we think that an early exchange of results and pitfalls can be very valuable by current and future users of this robotic system. Hopefully with an open approach and early reporting of results and pitfalls problem as with the Robodoc system can be avoided.

References
Clinical Results Of Navigated TKA For Posttraumatic Arthrosis

MAEGERLEIN S, FUCHS S, FASCHINGBAUER M, JUERGENS C, SCHULZ AP

Dept Trauma & Orthopaedics, Bg Trauma Hospital Hamburg, Germany

maegerlein@apschulz.de

**Introduction:** Posttraumatic degeneration of the knee joint poses difficulties for the implantation of artificial knee joints. Bony structures are often deformed, ligamentous balancing is often challenging. Trauma surgeons are often less exposed to large caseloads of primary osteoarthritis, compared to purely "elective" orthopaedic surgeons. On the other hand, posttraumatic knee arthrosis is often accompanied by severe deformity and axis deviation. The local soft tissue situation is often difficult after previous operations. In theory, navigated arthroplasty can overcome some of the problems in this setting.

**Materials and Methods:** Between 7/04 - 12/05 we treated 56 Patients with a mean age 62 yrs. (32-82). Forty-nine patients were available for follow up. All had a severe Arthritis of the knee joint due to trauma, 58% were male, in 51% the treatment was under the Workers injury compensation scheme. On average patients had 3.02 previous operations (1-9, including arthroscopies). The navigational system used is manufactured by PRAXIM (La Tronche/ France). It uses infrared-tracking and bone-morphing software. The implant was a mobile bearing LCS knee (DePuy/USA). Follow up included radiographs, clinical examination and the knee society scores. We used Torniquet, Redon-drains for 48hrs and single shot antibiotic prophylaxis. For 2 weeks partial weight bearing with 20 kg and 60° maximal flexion, then 2 weeks 90° was enforced. Study setup was prospective, follow up period on average 14.5 months (11-25 months).

**Results:** The mean “Cut to Stitch” time was measured between 55 to 145 min (av. 91). There was a clear learning curve.

Four times (8.1%) the navigation was terminated:
- surgeon suspicious about suggested cuts
- a tracker fixation screw broken
- femoral cut block missing on tray
- procedure converted to constrained TKA
- There was no failure of system hard- or software

As complications we saw two cases of DVT, one 1 wound infection and
one case of arthrofibrosis with loosening of the femoral shield (cement free,
changed to cemented). In two cases a retropatellar implant was required at 5
and 11 months

Preop. a.p. deviation was measured from 30° valgus to 22° varus (49% varus,
43% valgus) on a.p. radiographs. Postoperatively >90% of knee axis were
within 2° of the ideal axis as determined by the system.
The Extension deficit improved from 10,4° (0-30°) to 1,6° (0-10°). The flexion
improved from mean 94° (30-120°) to 102° (70-125°). The preop Knee Society
Score (KSS) was mean 20 pts (0-60), the KSS at F/U was mean 76 pts (42-95).
The functional Knee score was preop mean 46 pts (18-79), compared to postop
mean 78 pts (47-100). The combined Insall score at F/U was measured 154 pts.
The combined Knee Society Score improved mean by 87,7 points (19-152).

Discussion: Modern navigational systems can master even complex deformity,
the navigation is a helpful tool in TKA for posttraumatic deformity. Results are
inferior to TKA for other indications but the improvement step is equal. There
is a considerable learning curve of the procedure.

References
2. Fehring TK, Mason JB, Moskal J, Pollock DC, Mann J, Williams VJ. When
3. Hofmann AA, Heithoff SM, Camargo M. Cementless total knee arthroplasty in
morphing: 3D morphological data for total knee arthroplasty. Comput Aided Surg
2002;7-3:156-68.
5. Insall JN, Dorr LD, Scott RD, Scott WN. Rationale of the Knee Society clinical
Short Term Follow-up Of 91 Navigated Uncemented E.motion Knee Prostheses With A 350µm Plasma-spray Titanium Coating

SAMPATH SAC, DAVIES HG, VOON SH

The Bluespot Knee Clinic, The Classic Fylde Coast Hospital, Blackpool, UK

shameemsampath@hotmail.com

Introduction: Cementless total knee arthroplasty (TKA) implants were designed as an alternative to cemented implants. They were expected to provide long-term fixation without the fear of cement debris particle generation and cement degradation resulting in late prosthetic loosening and failure. However, critical studies revealed a unique set of complications, which included poor fixation as evidenced by frequent occurrence of radiolucent lines, aseptic loosening and osteolysis. [1]. At the same time, cemented prostheses continue to yield excellent results. To address some of the issues with cementless implants, porous metal devices have been produced. The Plasmapore® titanium coating represents over 20 years of clinical experience, mostly for cementless hip implantation [2]. The purpose of this follow-up study is to investigate the early results of Plasmapore® coating in Navigated cementless rotating platform TKA. Clinical outcome and morbidity rates are critically analysed with regard to prosthesis related incidents.

Materials and Methods: 277 patients who had consecutively undergone a Navigated TKA procedure with the e.motion knee endoprostheses were followed up at the Bluespot Knee Clinic in Blackpool, UK. Of these 277 patients, 91 received fully cementless knee TKA between May 2005 and September 2007. This version of the prosthesis is covered with a 350µm plasma-sprayed titanium layer.

51% of the group were men, and 49% women. They had a mean age of 69 (std dev 8, range 45-86) years at surgery and an average BMI of 30 (std dev 5, range 20-45). There were 50 right knees and 42 left knees.

All procedures were carried out by the senior author (SACS). The Orthopilot
navigation system was used to accurately restore the axial alignment of the implants. The mean operating time was 59 minutes (std.dev.14 min, range 39-121).

<table>
<thead>
<tr>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>69</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83</td>
</tr>
<tr>
<td>BMI</td>
<td>30</td>
</tr>
<tr>
<td>OP time (min)</td>
<td>59</td>
</tr>
<tr>
<td>preop. KSS (functional)</td>
<td>37</td>
</tr>
<tr>
<td>preop. KSS (clinical)</td>
<td>40</td>
</tr>
<tr>
<td>preop. Oxford</td>
<td>44</td>
</tr>
</tbody>
</table>

Tab.1: Basic preoperative data on 91 (87 patients for the Oxford Score) patients with a cementless e.motion knee prosthesis

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idiopathic osteoarthritis</td>
<td>85</td>
</tr>
<tr>
<td>Psoriasis</td>
<td>2</td>
</tr>
<tr>
<td>Posttraumatic osteoarthritis</td>
<td>2</td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
<td>1</td>
</tr>
<tr>
<td>Avascular necrosis</td>
<td>1</td>
</tr>
</tbody>
</table>

Tab. 2: Diagnoses

**Results:** The clinical outcomes from the 91 patients reported are derived from the routine follow up of post operative patients at the Bluespot Clinic. It is not a systematic recall of patients for a defined period after surgery. For various reasons not all patients return for an ambulatory follow-up. Therefore a missing follow-up examination does not mean that the patient is lost to follow-up. The report does not include radiological results, as this is not part of the regular review examination.

Out of the 91 patients who received cementless e.motion knee prostheses, 84 patients had at least 1 follow-up assessment. The average follow-up period for these 84 cases was 7 months (218 days).
Knee Society Score: The integral Knee Society Score (KSS), defined as the sum of functional and clinical KSS, was recorded for all 91 patients preoperatively and has a mean of 78 (std.dev.21, range25-124). At 3 months with 60 cases available for follow-up (including all follow-ups between 2 and 4 months) the KSS had increased to 182 (std.dev.19, range135-200). After 6 months (including all follow-ups between 4 and 8 months) the average KSS was 188 (std.dev.16, range127-200), taking into account 52 cases, and after 1 year (including all follow-ups between 8 and 16 months) the average of the KSS amounted to 193 (std.dev.13, range150-200), accounting for 20 cases. For the 2 year-assessment only 3 cases had already presented for follow-up. Their averaged integrated KSS was 198 (std.dev.1, range197-199). See Figure 1.

Oxford Score
The Oxford score was recorded for 87 of the 91 patients preoperatively. The average preoperative score is 44 (std.dev.6, range 27-56). After 3 months with 60 patients available for follow-up (all follow-ups between 2 and 4 months) the mean average Oxford score was 18 (std.dev.5, range 12-36). After 6 (4-8 months) months with 52 available cases and 12 months (8-12 months) with 18 cases the average Oxford scores were 15 (std.dev.0, range 12-32 for 6m., std.dev.1, range 12-28 for 12m.), respectively. The score was measured after 24 months for only 3 patients; the mean was 13 (std.dev.1, range12-14). See Figure 1.

Morbidity: There were 21 surgical complications. These were bleeding into 2 knees, 9 minor wound infections, 3 minor non-infectious wound problems (2 episodes of wound erythema and 1 small haematoma), 5 deep vein thromboses with 2 pulmonary embolisms, and 2 cases of Reflex Sympathetic Dystrophy. No prosthesis related problem or revisions occurred. The 7 morbidities not related to surgery include 4 problems in other weight bearing joints (hip and knee), one
patient suffering swelling and stiffness after a diabetic crisis, one patient with ataxia, and one fall 6 weeks post operatively causing a fracture of the lateral condyle with subsequent development of a valgus deformity.

Discussion: This study has collected and analyzed clinical data on cementless knees, coated with Plasmapore® with regard to prosthesis related incidents. Its purpose was to decide if this combination can lead to results comparable to the so-called “gold standard” of a cemented knee prosthesis implantation. During this retrospective analysis of 91 patients no complications related to the uncemented prostheses were seen. Specifically there are no signs of loosening, and no dislocations or subluxations of inserts. The results after the limited follow-up periods from 3 months up to 2 years are favourable and comparable with cemented designs in terms of clinical outcome, patient self assessment and survival.

A systematic 2-year follow up of the 91 patients, including a radiological analysis, is due to begin in the near future.

References
Rotation Of The Femoral Component In TKR - An Evaluation Of The Relevant Axes With Navigation And CT-Scan

SINZ SG¹, WEINHANDEL WE¹, G ERGELY GI¹, NEUMANN NC¹, SINZ SK²

¹ Orthopaedic Department, Hospital Saint John Of God, Eisenstadt, Austria
² Psychological Faculty, University Of Vienna, Austria

sinz@nextra.at

Introduction: Formulation of the question: The aim of navigated TKR is a neutral leg-axis with an exact balancing of the extension-gap and the flexion-gap. The rotation of the femoral component has a decisive importance for a good functional result, especially in high congruent knee-prosthesis. Between the epicondylar axis and the posterior condylar axis exists an individual relationship.

By doing a force-controlled balancing of the flexion-gap the relations between these two axis may change individually. In the first place we wanted to know how and how much the relations are changing. In the second place we wanted to find out if the values of the navigator are corresponding to the real values measured by CT-scans.

Materials and Methods: From January 2007 till January 2008 we operated on a collective of 50 patients with osteoarthritis in a standardized procedure using an anteromedial approach. The collective was unmatched, the leg-axis was maximum 20° varus and maximum 10° valgus. Patients with severe deformities were excluded. In our clinic we implant all over the year around 350 total knees. All study surgeons have a big experience with TKR. On preoperative CT-scans the epicondylar axis and the posterior condylar axis were recorded. In all cases we implanted a navigated emotion-prosthesis (Aesculap) with the orthopilot (Aesculap) by using a floating platform or a rotating platform. Every step of the navigation was recorded for the further comparison with the CT-data. The gap-balancing was done force-controlled with a spreader reaching around 85 Newton. On postoperative CT-scans we recorded the change of the relations between the epicondylar axis and the posterior condylar axis. We also compared the values of the CT with the values of the navigator.
The radiological measurement was executed by two independent radiologists using a spiral-CT with 1-mm-layers in a bone-window. To hold independence to the study surgeons the navigation-data were statistically prepared by the technician of the company. The statistic (t-test) has been conducted by a student of the University of Vienna.

**Results:** By doing a force-controlled balancing of the flexion gap the relation between epicondylar axis and posterior condylar axis changes highly significant (t-test = .000) in the direction of external rotation (0° to 7°, middle 3.3°). Extreme values are frequent. There is no significant difference (t-test = .393) between the measured data of the Navigator and the measured CT-data.

**Discussion:** With this prospective study we could show the change of the relations between epicondylar axis and posterior condylar axis in TKR using force-controlled instruments for the ligament balancing. Especially for high congruent prosthesis an exact balancing of the extension gap and the flexion gap is important. Extreme values are frequent and have to be considered exactly. Because there is no significant difference between the measured data of the Navigator and the measured CT-data navigation is a reliable option to get objective values. This research gives latest findings to optimize the rotation of the femoral component in TKR. To the opinion of the study-surgeons the results are valid for navigated and for manual instrumented TKR. Reproducible results are following to an exact measurement in navigation and CT.
Navigated Soft Tissue Management In Severe TKA Cases

VOON SH, DAVIES HG, SANGSTER M, SAMPATH SAC

The Bluespot Knee Clinic, The Classic Fylde Coast Hospital, Blackpool, UK
shameemsampath@hotmail.com

Introduction: Severe total knee arthroplasty (TKA) deformity has been defined as ≥10° valgus or ≥15° varus off the neutral axis [1]. These deformities present extreme challenges to surgeons in deciding the extent of soft tissue releases without affecting stability. The crucial factor in TKA is to maintain equal flexion and extension gaps with stability. The approach to these problematic knees requires the medial and posteromedial releases in varus knees and lateral and posterolateral releases in valgus knees.

It is well documented that the post-operative corrections gained following TKA in severe varus deformities are not as good as those in well aligned knees, and that the surgery can take considerably longer [2]. This is regardless of whether a posterior cruciate retaining or cruciate sacrificing implant is used.

Patients with large preoperative deformities also perform less well postoperatively when compared to patients with little or no initial deformity [3]. Many studies have described the importance of aligning the components to within 3 or 4 degrees of the neutral axis to prevent aseptic loosening or excessive polyethylene wear that may necessitate revision surgery [4].

Soft tissue imbalance in these cases can lead to instability of an unconstrained rotating platform and the chance of polyethylene “spin out”.

The introduction of navigated surgery with soft tissue management allows the surgeon to perform real time soft tissue releases to achieve ligament balance and therefore stability.

The purpose of this study was to review the results achieved with the use of the rotating platform e.motion TKA with Navigated soft tissue management in severe deformity.

Materials and Methods: This was a prospective study that included all patients having a TKA over 35 months. All severe knee deformities were included. A single surgeon (SACS) previously experienced in non-navigated TKA
implanted the e.motion uncemented rotating platform TKA (B.Braun-Aesculap, Tuttlingen, Germany) using the OrthoPilot® Navigation system version 4.2 (B.Braun) with soft tissue management. Surgery was carried out using a pneumatic tourniquet. The tourniquet was inflated to 350mmHg after the limb was draped and elevated, and was deflated immediately after the wound had been closed and covered with a sterile adhesive dressing. The tourniquet times were recorded automatically by the tourniquet machine which was managed by the anaesthetic staff. The medial parapatella approach was used for all varus knees and the lateral parapatella approach for all valgus knees. After tibial resection, all osteophytes are always removed. A spreader was used to measure the flexion-extension gap. The intention is to achieve a balanced flexion-extension gap with soft tissue release as indicated. Stepwise releases were done and registered in 0° extension and in 90° flexion until the alignment was within ≤ 3°.

**Results:** There a total of 13 severe Varus deformities and 17 severe Valgus deformities.

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Op</td>
<td>18.6° (5.4)</td>
<td>15°</td>
<td>35°</td>
</tr>
<tr>
<td>Post Op</td>
<td>0.7° (0.8)</td>
<td>0°</td>
<td>2°</td>
</tr>
</tbody>
</table>

Figure 1. Comparison of PreOp and PostOp Varus deformities

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Op</td>
<td>13.5° (3.6)</td>
<td>10°</td>
<td>22°</td>
</tr>
<tr>
<td>Post Op</td>
<td>1.3° (2)</td>
<td>0°</td>
<td>7°</td>
</tr>
</tbody>
</table>

Figure 2. Comparison of PreOp and PostOP Valgus deformities

This improvement in the alignment of the mechanical axis is statistically significant, for both the Valgus and Varus knees. p<0.0001 (Student’s t test).

**Discussion:** Soft tissue balancing was technically more difficult in the lateral approach than the medial approach. In one case we accepted an alignment of 7° because of tension on the lateral popliteal nerve from scarring due to a previous osteotomy.
Performing soft tissue releases to achieve to within 3° of the neutral axis is not a problem as navigation provides reliable and precise instrumentation. The problem is to determine extent of release without jeopardising stability.

Discussion: Introduction of Navigated TKA has dramatically changed the approach to soft tissue releases. It provides real time visualisation and quantification of the effect of sequential soft tissue release in TKA. This appears to extend the indications for implantation of the Rotating Platform Emotion TKA.

References

1) David Beverland. Management of the severe varus and valgus knee using the low contact stress rotating platform. Orthopedics. 2006 Sep; 29 (9 Suppl): S60-3 1700215
Bone Morphing System For Surgical Optimization In Total Knee Arthroplasty: Comparison Of Initial Outcome With Conventional Procedure

WU H1,2, VAN DRIESSCHE S1, GOUTALLIER D1

1 Department of Orthopaedic and Traumatic Surgery, Henri Mondor Hospital, Créteil, France
2 Department of Orthopedic Surgery, People’s Hospital of Guangxi, Guangxi, China
wuhaorthop@yahoo.com.cn

**Introduction:** Since the introduction of computer-assisted orthopedic surgery (CAOS) in total knee arthroplasty (TKA), more and more comparative reports have showed the advantages of this technique superior to conventional TKA, not only in accurate alignment of the lower limb and osteotomy, components position, but also the assessment of ligament balance and knee kinematics. Whether a Bone Morphing based image-free Ceravision® system can improve lower limb axis alignment, prosthesis rotational position and ligament balance to obtain good clinical initial outcome is the objective of the current comparative study.

Participants: Between November 2002 and June 2003 in Henri Mondor Hospital of France, 21 patients were operated by an experienced senior surgeon (GD) via primary TKA, with posterior stabilized total knee prosthesis (Hermes® Ceraver, France), using a “Bone Morphing” Ceravision System (Ceraver, France). 20 patients were operated by the same surgeon with the same type of prosthesis using conventional technique. All patients suffered from gonarthrosis received the primary arthroplasty were enrolled in the study. In navigated group A, 21 patients included 5 men and 16 women with an average age of 72.4 (range: 64-79) years. In conventional group B, 20 patients included 6 men and 14 women with an average age of 73 (range: 65~83) years. Preoperatively in group A, there were 14 varus knees (65%) and 7 valgus knee (35%); in group B, there
were 15 varus knees (69%) and 5 valgus knee (31%). Statistic analysis did not show significant difference, p>0.05.

**Materials and Methods:** To evaluate and compare the preoperative, intra-operative and postoperative relative image data in navigation group, and to assess and compare the postoperative alignment and ligament balance, the mobility of operated knees in three months postoperative follow-up as the initial clinical outcomes between navigated and conventional groups. Main outcome measures: Postoperative prosthesis position, alignment deviation, range of motion (ROM), frontal laxity, stability and patella complication of the operated knee.

**Results:** All patients of the two groups were included in this clinical study and analysis. All femoral, tibial and patella components were implanted in satisfactory position in all patients. In navigated group 21 knee, preoperative 14 knees being with varus (65%), lower limb alignment deviated with valgus 0.16° (varus1°~valgus2°) postoperatively, in conventional group 20 knees, preoperative 15 knees being with varus (69%), lower limb alignment deviated with varus 0.9° (varus 3.5°~valgus3°) postoperatively, there was not significant deference, p>0.05; in navigated group 21 knee, preoperative 7 knees being with valgus (35%), lower limb alignment deviated with valgus 0.14° (varus2°~valgus3°) postoperatively, in conventional group 20 knees, preoperative 5 knees being with valgus (31%), limb alignment deviated with valgus 0.25° (varus 1°~valgus2°) postoperatively, there was not significant deference, p>0.05.

In three months post-operative clinical check-up for the comparisons of initial result, mean flexion angle measured as the range of motion (ROM) in group A =115°(105°~130°), in group B =109.4° (90°~130°) , the difference is not significant, p =0.06; frontal laxity check-up showed internal laxity 0.27cm (0.2~0.5) /external laxity 1.7cm (1.0~2.5) in group A, while internal laxity 0.27cm (0.1~0.5) / external laxity 2.23cm (1.0~3.0) in group B, the difference is significant, p =0.03. In both groups there were not any patella instability and other complications influencing the clinical outcome observed.

**Discussion:** TKA is a challenging task that aims at achieving a pain free, stable and mobile joint. To obtain successful outcome of TKA surgery, there are several important surgical techniques criteria, including ① accurate restoration of the lower limb mechanical axis alignment within a range of ±3° in frontal view, ② proper rotational alignment of the prosthesis in axial plane, ③ achievement of symmetric rectangle flexion-extension gap and ligament balance.
Both mobility and stability are essential factors for long term survivorship of implants and this can only be achieved if the implants are properly aligned with the mechanical axis of the lower limb and if two ligament complexes are perfectly managed, the tibia-femoral and patello-femoral ligament complexes. From a mathematical point of view, performing a knee joint replacement is therefore a rather complex optimization problem in which the best compromise must be found in order to allow a full range of motion with perfect mobility/stability in both the femoro-patellar and the tibio-femoral joint.

Stindel et al. described Bone Morphing as an accurate, fast, and user-friendly method that can provide morphogenic as well as geometric data. Bone Morphing approach can offer significant improvements because it enables the surgeon to plan a real and global tradeoff taking into account all morphologic and functional parameters, including knee balancing and accurate lower limb axis alignment quantitatively. In the optimization loop, it helps to obtain a good compromise between the HKA axis (monitored by the computer) and the balance of the collateral ligaments. If such a compromise cannot be achieved, then a release of the collateral ligament must be performed, or a condylar osteotomy may be aided.

In practice, the operator will modify the osteotomy, chose the proper implant size, position and rotation with respect to the lower limb alignment and the flexion-extension rectangle gap via the surgeon-friendly interface benefited of 3D geometric and morphologic data obtained by the Bone Morphing technique. The surgeon can perform the exact rotation degree alignment, realize collateral ligament release of the concave side and adjust the balancing of flexion gap according to the individual patient, to get an optimized result quantitatively and objectively.

After a learning curve, this system would enable surgeon to facilitate the TKA procedure and to achieve a good result.

Bone Morphing navigated system allows for optimization of lower axis alignment and prosthesis rotational position as well as ligament balance in TKA, which impacted on the clinical outcome. When using Bone Morphing navigation system we could profit of ① the accuracy for lower limb axis alignment, ② efficiency for symmetry flexion-extension gap and ligament balance and ③ accuracy for components rotational alignment for the aim of TKA optimization.
Computer Navigation Did Not Improve Alignment In A Lower-volume Total Knee Practice

YAU WP, CHU KY, ZOU JL, TANG WM, NG TP

Department Of Orthopaedics And Traumatology, Queen Mary Hospital, Hong Kong, China

peterwpy@hkucc.hku.hk

Introduction: The aim of this paper was to report the radiographic result of a series of computer navigation TKA done in a hospital with a lower-volume total knee practice. The primary research objective was to examine whether there was an improved accuracy in the post-operative radiographic alignment of the implanted prosthesis performed using computer navigation TKA versus conventional instrumentation TKA as judged by (a) overall limb alignment relative to the mechanical axis of the lower limb; (b) femoral component alignment relative to the mechanical axis of femur and (c) tibial component alignment relative to the mechanical axis of tibia.

Materials and Methods: To assess the improved accuracy in the recreation of the mechanical alignment in the TKA performed using computer navigation, a retrospective review of the surgeon’s experience before and after adopting computer navigation was performed. The case series was a consecutive series constituted by the author’s initial experience of using computer navigation technique from January 2004 to October 2006. The control series was a selected series from matching cases of the author’s previous experience in using conventional instrumentation (femur intramedullary alignment guide and tibial extramedullary alignment guide) from January 2001 to December 2004. Fifty-two consecutive image-free computer navigation TKAs were performed by a single surgeon from January 2004 to October 2006. This formed the case series. The author had experience performing 100 conventional technique TKAs. The average number of TKAs performed each year was approximately 25. The operations were performed using either BrainLAB Vector Vision (15 knees) or Ci (39 knees) image-free navigation TKA software. There were a total of eight males and 25 females. Fourteen patients received unilateral TKAs.
Nineteen patients received one-stage sequential bilateral TKAs. We operated on 49 knees because of primary osteoarthritis of the knee and three knees because of rheumatoid arthritis. We compared this case series with a historical control series of 52 TKAs performed by the author using a conventional instrumentation technique (femur intramedullary alignment guide and tibia extramedullary alignment guide). No significant differences were found between the two series in terms of age, gender, body height, the diagnosis leading to the operation, or the preoperative lower limb deformity noticed in the standing coronal plane radiographs of the whole lower limb. We performed all of the radiographic measurements using postoperative standing radiographs of the whole lower limb. Two independent observers were involved. Repeated measurements of the radiographs were done with at least a 1-week interval between. We defined the ideal alignment of the mechanical axis of the lower limb as a collinear line joining the center of the hip joint, the center of the prosthetic knee joint, and the center of the ankle joint. The ideal alignment of the femoral prosthesis and the tibial prosthesis in the coronal plane were defined as an alignment perpendicular to the mechanical axis of the corresponding bone. A surgical outlier was defined as a deviation of more than 3° from the ideal alignment. The results of the two series were compared. The null hypothesis stated that there was no difference in the postoperative overall limb alignment measured in the standing X-rays of the whole lower limb between computer navigation TKA and the conventional technique TKA. This was examined by independent t test. Statistical significance was assumed if p < 0.05. The factors that influenced the radiographic alignments of the navigation series were studied.

**Results:** There was no improved accuracy in the post-operative radiographic alignment of the implanted prosthesis performed using computer navigation TKA versus conventional instrumentation TKA as judged by the overall alignment relative to the mechanical axis of the lower limb (computer navigation series, varus 1.3°, SD 3°; historical control series, varus 0.3°, SD 3°; p = 0.1, independent t test). Outliers of more than 3° were observed in 29% of the navigation series and 25% of the conventional jig-based series (p = 0.356, Chi square test). There was no statistical difference between the two groups in terms of the error of the alignment of the femoral prosthesis in the coronal plane (Post-operative distal lateral femoral angle in the Navigation series: 90.3°, SD 1.9°; Control series: 90.3°, SD 1.7°; p = 0.999). If a surgical outlier was defined as a deviation of more than 3° from the ideal position, 94.3% of the femoral components in both the navigation and conventional technique groups were considered to have satisfactory alignment. The tibial tray was implanted in a slightly more varus alignment in the computer navigation group (postoperative
proximal medial tibial angle, 89°, SD 2°) than in the conventional technique group (90°, SD 2°) \( (p = 0.01, \text{ independent } t\text{ test}) \). Outliers of more than 3° were found in 13.5% of the tibial component in the navigation group and 9.6% in the control group \( (p = 0.186, \text{ Chi Square test}) \). The significant factors which affected the post-operative overall mechanical alignment in the navigation series included the severity of the pre-operative deformity \( (p = 0.028, \text{ independent } t\text{ test}) \), the amount of error in the execution of bone cuts \( (p = 0.012, \text{ Pearson correlation coefficient } = 0.258) \) and the experience of the surgeon \( (p = 0.023, \text{ independent } t\text{ test}) \)(Figure). The result of the navigation series compared favourably with the control series if the surgeon’s initial 20 navigation TKRs were removed from the overall case series. The amount of satisfactory lower limb alignment in the last 32 navigation TKRs was 81% (versus control group: 75%; \( p = 0.166, \text{ Chi square test} \)). Only 3% of extreme outlier of more than 5° was found (versus 12% in the control group; \( p = 0.006, \text{ Chi square test} \)).

**Discussion:** The accuracy in the post-operative radiographic alignment of the implanted prosthesis was not improved by adopting computer navigation technology in a hospital with a lower-volume total knee practice, as judged by (a) overall limb alignment relative to the mechanical axis of the lower limb (Case 71% versus Control 75%); (b) femoral component alignment relative to the mechanical axis of the femur (Case 94.3% versus Control 94.3%) and (c) tibial component alignment relative to the mechanical axis of the tibia (Case 86.5% versus Control 90.4%).
Electromagnetic Navigation In Total Knee Arthroplasty - Comparison Of Our First 100 Cases To Our Last 100 Cases

WON YY¹, SHIN DS¹, PIAO TH¹, HUR JH², CUI WQ²

¹ Department Of Orthopaedic Surgery, Ajou University Hospital, Suwon, Korea
² Ajou University, Graduate College Of Medicine, Suwon, Korea

thrtkr@ajou.ac.kr

Introduction: Electromagnetic Navigation(EM) system has been introduced in total knee arthroplasty to increase the accuracy of lower limb alignment and positioning of the implant. EM navigation systems offer several potential advantages over their infrared counterparts. To our best knowledge, there have been scarce clinical results reported. In order to obtain optimal results, a certain period of learning curve may be necessary. We have compared our first 100 cases of total knee arthroplasty to our last 100 cases in order to verify the clinical accuracy, efficacy and learning curve.

Materials and Methods: From July 2006 to November 2007, 138 patients underwent 200 serial primary TKA operations by a single surgeon with the assistance of Electromagnetic Navigation system. The 200 TKA cases were divided into two groups; the first 100 and the next 100 cases. We have compared the deviation in postoperative mechanical axis and angles of femoral and tibial component position(α°, β°, and γ°) in addition to the outlier percentage of post-mechanical axis between the two groups. We used the independent sample t-test to verify our results.

Results: The deviation in angle of postoperative mechanical axis was significantly lower in the last group than the first group; 2.0633 vs. 2.6944. (p=0.0145) respectively. The deviation of α° was significantly lower in the last group than the first group; 1.1597 vs. 1.6778. (p=0.005) respectively. The deviation of β° was lower in the last group than the first group; 1.3475 vs. 1.2115, but this value was not significant. (p=0.849). The results of the value γ° proved to be more towards extension in the first group and more towards
flexion in the last group, yet these values were not significant (p=0.159). The outlier percentages of postop-mechanical axis between two groups were significantly different.

**Discussion:** The navigation system most often used in studies is an optical system with an infrared camera. Many authors have reported the efficacy of optical navigation system. It has been known to increase the accuracy of lower limb alignment and positioning of the implant while decreasing the outlier percentage of postoperative mechanical axis. The large transmitter, however, for this system requires bicortical pins, which would result in stress fracture through the drill-holes in bone. In addition, another skin incision is needed for the transmitter. A new navigation technique using electromagnetic signals has been introduced with advantages including small transmitter size, although its signal is often distorted by metal devices used in the operative field. Our hypothesis was therefore that the EM system could lead to better alignment of the leg and positioning of implants than traditional method with comparable learning curve. In summary, the EM navigation system can lead to better alignment of the mechanical axis of leg and positioning of femoral implants in coronal view compared to conventional method, although it can’t prevent outliers in all case. And also our experience suggests that in order to obtain such results, however, a certain period of learning curve may be necessary. Several valuable surgical tips specific to this technology were obtained enduring our learning curve and will be presented.
Orientation And Position Of The Femoral Component During TKA - What Matters?

KÖNIG C¹, SHARENKOVA¹, MATZIOLS G², PERKA C², DUDA GN¹, HELLER MO¹

¹ Julius Wolff Institute And Center For Musculoskeletal Surgery, Charité - Universitätsmedizin Berlin, Germany
² Center For Musculoskeletal Surgery, Charité - Universitätsmedizin Berlin, Germany

cristian.koenig@charite.de

Introduction: The post-operative biomechanics of the knee joint are of critical importance for the function and long time success of total knee arthroplasty (TKA). An important aspect in characterising the post-operative biomechanics are the joint contact forces in the tibio-femoral and patello-femoral joint. An unphysiologically high joint contact force can cause increased PE-wear or may result in limited function and post-operative pain. During surgery, the orthopaedic surgeon has six independent degrees of freedom to position and orientate the femoral component. These are the angular orientations such as flexion-extension, the varus-valgus and internal-external rotation as well as the translations in medio-lateral, anterior-posterior and superior-inferior direction. So far very little information is available on the individual influence that these parameters have on the joint contact forces. Such knowledge is essential for determining which parameters need to be most carefully monitored intra-operatively. The aim of this study was therefore to assess and rank the relative influence of each individual parameter on the joint contact forces.

Materials and Methods: A virtual implantation of a knee endoprosthesis (Columbus UC, Aesculap, Tuttlingen, Germany) was performed on musculoskeletal models of four patients. The individual gait pattern of these patients reflected the post-operative situation as determined using a geometric approach to describe the prosthesis’ kinematics. For all patients tibio-femoral and patello-femoral contact forces were calculated for the anatomical reconstruction of the knee joint during two functional activities of daily living, i.e. normal walking and stair climbing. In a next step the orientation
and position of the femoral component was varied in each of the six individual parameters. The flexion of the femoral component was varied in a range of ±5° from its orientation in the anatomical reconstructed knee, whilst the varus-valgus orientation was varied in a range of ±10°. The internal-external rotation ranged from 5° internal to 10° external rotation. In medio-lateral and antero-posterior direction the component was shifted ±5mm and in superior-inferior direction ±10mm. Contact forces at the tibio-femoral and patello-femoral joints were calculated for each parameter combination. The relative influence of an individual parameter was defined as the average error that occurred when a variation to the specific parameter of interest was either applied or the value of the parameter remained fixed.

Results: The superior-inferior location of the femoral component, also referred to as the location of the joint line, showed the largest relative influence with a contribution of 32%, followed by the varus-valgus orientation (23%). Anterior-posterior translation had a larger influence (19%) than the translation in medio-lateral direction (13%). The influence of the internal-external rotation was dependent on the activity and was higher during walking (18%) than during stair climbing (8%). The flexion of the femoral component showed the smallest influence (4%) on both tibio-femoral as well as patello-femoral joint contact forces.

Discussion: In this study we were able to characterize the relative influence of the femoral component’s rotational and translational degrees of freedom on the post-operative joint contact forces at both the tibio-femoral as well as patello-femoral joint. The strongest change in joint contact forces was linked to a change in the location of the joint line (32% relative influence) followed by the the varus / valgus orientation and the anterior-posterior location of the femoral component. To reduce the risk of post-operative pain and limited function resulting from pathologically increased tibio-femoral or patello-femoral joint contact forces, these parameters should be carefully monitored during surgery.
Prospective Comparative Study between Navigation Assisted Minimally Invasive and Conventional Techniques in Bilateral Total Knee Arthroplasties

SONG EK, SEON JK, PARK SJ, KIM YJ, HUR CI

Center For Joint Disease, Chonnam National University Hwasun Hospital, Jeonnam, Korea

eksong@chonnam.ac.kr

Introduction: Computer-assisted navigation systems were introduced to improve component alignment accuracies1-4, and a number of studies have concluded that leg and component alignment are improved in TKA performed using navigation systems. Therefore, to solve the challenges caused by the limited surgical view in minimally invasive TKA, we considered combining the accuracy of navigation systems with minimally invasive surgery (MIS). This prospective study was undertaken to compare the clinical and radiological results achieved using navigation (Orthopilot®: Aesculap, Tuttlingen, Germany) assisted minimally invasive (NA-MIS) and conventional (CON) techniques in bilateral total knee arthroplasty (TKA).

Materials and Methods: Forty-two bilateral patients with a minimum 2-year follow-up who were available for study after NA-MIS TKA were included in this study. Average patient age was 64.2 years (range: 48-82 years), and the study group comprised 9 males and 33 females. Primary diagnoses included osteoarthritis in all patients, and no patient had undergone a previous knee operation. Minimally invasive surgery (MIS) was defined as surgery performed via a curvilinear skin incision medial to the patella from 2 cm proximal to the superior pole of the patella to 2 cm below the joint line, using a mid-vastus approach without patella eversion. The length of the skin incision varied between 9 and 13 cm. Clinical evaluations (ROM, HSS and WOMAC scores) were performed at 3 and 6 months and at 1 & 2 year postoperatively. Patient
subjective preferences and radiological accuracies were compared at 1 year postoperatively.

**Results:** Preoperative HSS scores were 68.5 in the NA-MIS group and 66.5 in the CON group, and these scores improved to 93.6 and 92.5 at 1 year postoperatively, respectively. Knees had a higher average HSS score in NA-MIS group than in the CON group till six months, but not after nine months postoperatively. In terms of WOMAC scores, pain scores in the NA-MIS group were better up to nine months postoperatively, but not at one & 2 year postoperatively, and total WOMAC scores were better up to six months, but not after nine months postoperatively. ROM was comparable in both groups at all times. However, more patients preferred NA-MIS sides than CON sides. Radiological results demonstrated no difference between the mean values of the two groups, although the NA-MIS group contained fewer outliers than the CON group.

**Discussion:** We conclude that NA-MIS TKA using a „mini-midvastus“ approach results in better knee functional scores after TKA than CON-TKA up to 6 or 9 months postoperatively. However, no differences in any functional parameters were evident at one year postoperatively. NA-MIS TKA had fewer prosthetic alignment outliers than CON-TKA. A larger cohort and longer term studies will be needed to determine if this reduction in outliers results in an improvement in prosthetic survival.

**References**

Navigated Hip Resurfacing Without Using A Tracking System - Back To Stereotactic Navigation?

De La Fuente M1, Belej P1, Strake M1, Mumme T2, Radermacher K1

1 Chair Of Medical Engineering, Helmholtz-institute For Biomedical Engineering, RWTH Aachen University, Aachen, Germany
2 Department For Orthopaedics, Aachen University Clinic, RWTH Aachen University, Aachen, Germany

fuente@hia.rwth-aachen.de

Introduction: The introduction of computer-assisted navigation systems has led to a higher reproducibility and lower interobserver variability of many orthopaedic and trauma applications. These systems, mainly based on optical tracking systems, together with preoperative CT-Data, intraoperative calibrated x-ray images or deformable statistical models enable three-dimensional planning and navigation. Therefore, the surgeon is supported by a real-time feedback during implantation procedures. In many cases, as for example for the navigated drilling of the guidance-pin of hip resurfacing implants, only simple trajectory navigation has to be performed. The question arises, whether for simple trajectory navigation tasks the use of expensive navigation systems is required or, if similar to stereotactic surgery, simple mechanical devices can be used instead.

Materials and Methods: A new fluoroscopy based approach has been developed which is able to determine the spatial correlation (extrinsic calibration) of multi-planar 2D x-ray images only by means of image information of a small local calibration phantom without the need of any tracking technology. Using the system for hip resurfacing, an intraoperative three-dimensional planning of the position, orientation, and size of the implant within at least two x-ray images is possible. To avoid perforations or Notching of the femoral neck, a safety-zone can be defined. The planning result, which is the defined trajectory of the implant shaft, is than transformed into the operation site by a manual adjustment of a drill guide being part of a calibrated mechanical positioning device.
As the system determines the extrinsic calibration parameters from image information, for x-ray dewarping and camera calibration the commonly used approach having overlaying markers can not be utilised. Instead, a pre-calibration of these parameters is used.

The evaluation of the system concerned two main aspects. On the one hand, the feasibility and accuracy was evaluated, while on the other hand, the robustness of the approach using just a simple pre-calibration was analyzed. The in-vitro evaluation of a prototype was performed using a foam model. Simulating the drilling of the guidance pin for a resurfacing implant, different entry points (N=16) as well as different orientations (N=8) of the trajectory were performed. To verify the accuracy of the system, the realized drill holes (3.2mm) were extracted by two perpendicular calibrated x-ray images and compared to the planned trajectory concerning positioning and angular accuracy.

To evaluate the robustness of the approach against magnetic field distortions and deflections of the c-arm, pre-calibration parameters of eight different c-arm (Siemens ISO-C 3D) orientations were compared.

**Results:** Initially, the accuracy of different entry points of the trajectory was determined for parallel trajectories equally distributed in the entire workspace of the mechanical positioning device. The mean positioning accuracy was 0.46 mm (max. 0.93 mm), the mean angular accuracy 0.65° (max 1.0°). Changing the orientation of the trajectory to maximum possible angles of the device, the mean positioning accuracy was reduced to 0.48 mm (max. 1.09 mm) and the mean angular accuracy to 1.03° (max. 1.75°).

Changing the data of the pre-calibration to eight c-arm positions and orientations, for which maximal deviations were expected, no explicit difference could be observed. Figure 1 shows the positioning and angular accuracy for drill holes with maximum angular orientations of the trajectory in boxplots, where boxplot (1) represents the measurement using the adequate calibration parameters, and boxplots (2) to (9) represent measurements using a pre-calibration in different c-arm positions and orientations, for which only slightly different results were obtained.
**Discussion:** It could be shown that for a reproducible and exact navigation of hip resurfacing implants, no external tracking system is necessary. Furthermore, the fluoroscopy based system is robust against magnetic field distortions and deflection of the c-arm. The order of magnitude of the achieved accuracy also shows, that using the new approach potentially better results can be achieved compared to systems based on optical tracking (cp. [1,2]).

Besides the presented application for hip resurfacing, the system could be modified to fit for other applications of trajectory navigation, as for example the navigation of pedicle screws.

**References**


Computer-assisted Placement Technique In Hip Resurfacing Arthroplasty: Improvement In Accuracy?

KRÜGER SI, ZAMBELLI PY, LEYVRAZ PF, JOLLES BM

Hôpital Orthopédique De La Suisse Romande, Centre Hospitalier Universitaire Vaudois, University Of Lausanne, Lausanne, Switzerland

sandra.i.krueger@gmx.net

Introduction: The purpose of the presented study was to find out whether by using a navigation system the preparation of the femoral head and the positioning of the femoral component could be made easier and more precise. Another aim of the study was to evaluate if navigation technology allows by its more accurate placement of the components to re-establish the normal hip biomechanics.

Materials and Methods: Hip Resurfacing is primarily intended for younger, active patients, who can benefit from the likely longevity of the device. It also offers improved stability, which may allow greater levels of post-operative activity than are normally achieved with conventional hip replacement. Resurfacing of the can be obtained in the treatment of osteoarthritis and osteonecrosis large Ficat Stage II, Ficat Stage III and early Ficat Stage IV lesions in the young patient. Hip resurfacing received a renewed boost through the introduction of the BHR (Birmingham hip resurfacing) system. Among the most remarkable improvements are the metal on metal bearing as well as the equipment for the exact positioning of the femoral component through guided drilling, reaming and an insertion of the implant.

Although Hip Resurfacing implants have been in clinical use since 1991, computer navigation for this procedure has only been developed recently. Computer-assisted surgery is an evolutionary step in performing hip replacement surgery. The conventional guiding system seemed not to be optimal. The freehand positioning of the drill guide is difficult, time-consuming
and imprecise. Especially intending a very steep (valgus) implantation of the femoral component is at high risk for erosion of the femoral nec cortex (“femoral notching”).

Methods: Eighteen patients operated on by the same surgeon for Birmingham hip resurfacing arthroplasty were matched by sex, age, BMI, diagnosis and ASA score. For 9 patients the surgeon used the computer assistance and the other ones were operated with the regular ancillary (mechanical guide). Pre-operative planning was done on standard AP and axial radiographs of the hip as well as CT scan views for the computer assisted surgeries. The final position of implants was evaluated by the same X-Rays for all patients. The outcome was assessed using Harris Hip Score (HHS) and WOMAC score. The follow-up period was at least 1 year (mean 18 months). No patients were lost to follow-up. Statistical analysis was done using non-parametric tests at the 0.05 level of significance.

Results: No difference between both groups in terms of femoral component position was observed (p>0.05). There was no difference in femoral notching too. A trend for a better cup position was observed for the navigated hips in comparison with the freehand surgery, especially for cup anteversion (mean 19° for the navigated hips, 31° for the freehand ones). There was no additional operating time for the navigated hips.

Discussion: Hip navigation for resurfacing surgery may allow improved visualization and hip implant positioning, but its advantage will probably be more obvious with mini-incisions than with regular incision surgery. There are disadvantages to navigational systems, including increased cost and the possibility of error from computer malfunction or inappropriate commands. Outcome-based research and long-term follow-up are necessary to assess the clinical and economic impact of a minimally invasive approach to hip resurfacing. There is also a need for defined criteria to determine which patients might benefit from this surgical approach.
Metal-on-metal Resurfacing Of The Hip With Kinematic Navigation

PINK M\textsuperscript{1}, PINK T\textsuperscript{2}, JANECEK M\textsuperscript{2}, LISY M\textsuperscript{1}

\textsuperscript{1} Department Of Orthop. Surgery, Hospital, Trebic, Czech Republic
\textsuperscript{2} Department Of Orthop. Surgery, Traumatological Hospital, Brno, Czech Republic

miloslav.pink@nem-tr.cz

**Introduction:** In the present study we evaluate first short results of the 82 Articular Surface Replacements (ASR) of the hip join with kinematic navigation. The main purpose of the study was to analyze the functional, clinical and radiographic outcomes.

**Materials and Methods:** Between March 2006 and March 2007 we performed 82 resurfacing of the hip. There have been operated only unilateral hip in every patient. In aal cases we used Articular Surface Replacement of the Hip Joint (ASR-DePuy) with kinematic navigation (Ci system). It is a hybrid prosthesis with cementless acetabular and cemented head. We prefer anterolateral approach. All patients were operated by two surgeons. The surgeon perform the surgery with 3 assistants, third assistant is responsible for the position of the leg. Our group included 47 women and 35 men. Patients, mean age at surgery was 68.2 years (55-73y). The indication for resurfacing was just primary osteoarthritis. The bone cysts were not larger that 5mm on preoperative X ray picture. Clinical evulations were conducted using the Harris Hip Scoring system. Imaging studies: AP,axial X rays.

**Results:** Patients were follewed for an average 12 months postoperative (7-20 months). The average postoperative Harris Hip Total Score was 97% and 98% of the patients were in the good to excellent range of the 80-100 points. No patients were lost to follow-up. We noted a greater range of movement, faster postoperative rehabilitation and shorter time of hospitalization compared with traditional total hip arthroplasty. There were no cases of neurological complication, deep infection, wound dehiscence or dislocation or femoral neck fractures. Blood loss after resurfacing is comparable with standard total hip arthroplasty.
We note any correlation in clinical results to age or sex of patients. All X-rays refer correct position of femoral component in both projections.

The benefits of resurfacing were not fully realized with early prosthetic design due to a number of complications. Teflon on teflon, metal on polyurethane, ceramic on ceramic implants were associated with high wear rates. Furthermore, implant loosening and femoral neck fracture were common and some authors were reported that resurfacing was associated with an increased risk of the femoral head necrosis. In recently time, it is renascence of this method due to development of metallurgy and design prosthesis. The big role is using of the computer navigation, especially for direct of the stem of femoral component due to avoid femoral neck fracture. Computer navigation can be helpful to short of the learning curve. However surgeon must be educated in the technique of performing standard hip arthroplasty. Our experiences with Articular Surface Replacement of the Hip Joint (ASR-DePuy) powered by Ci navigation system are good, but long term followup will be continued.

**Discussion:** Articular Surface Replacement of the Hip Joint with modern design, reproductible instrumentation and kinematic navigation can eliminate the previous cause of early resurface failures and loosening. The patient selection must be strict regarding. The kinematic navigation defines precise position of the components of ASR. Due to results of our study, we can advise resurfacing with using of the Ci navigation in a strict indication as perspective surgery method of the hip osteoarthritis. A continued long term followup is necessary after minimum 10 years.
Laboratory And Pilot Study Of Customized Jigs For Distal Radius Osteotomy

MA B¹, KUNZ M¹, LING M¹, RUDAN JF², ELLIS RE³, ABOLMAESUMI P³, PICHORA D²

¹ Human Mobility Research Centre, Kingston, Canada
² Kingston General Hospital, Kingston, Canada
³ Queen’s University, Kingston, Canada
mab@cs.queensu.ca

Introduction: Customized jigs manufactured using rapid prototype techniques have been proposed for procedures such as total knee arthroplasty, spine surgery, and hip resurfacing [1-3]. We have conducted a laboratory trial and pilot clinical study to evaluate the feasibility of using custom jigs for distal radius osteotomy performed using fixation-based surgery [4].

Materials and Methods: We used computed tomography (CT) scans and planned corrections of 8 patients who had previously undergone computer-aided distal radius osteotomy (DRO). Virtual models of each radius were computed from the CT scans. A hard plastic (ABS) model of each deformed radius was fabricated using a rapid prototyping machine. A silicone rubber mould of each radius was produced and urethane plastic phantoms were cast from the moulds. Two customized jigs, designed to mate with the surfaces of the radius exposed during surgery, were fabricated using the rapid prototyping machine. The first jig was designed to guide the placement of the screw holes for a Synthes 3.5 mm locking compression plate (LCP) on the uncut radius. The second jig was designed to guide the shaping of distal surface using a Forstner drill bit; both the location and the depth of milling were guided by the jig. The jigs are shown mated to a distal radius phantom in Figure 1.

Two users were each presented with ten phantoms in a randomized order. Each user was asked to perform a DRO using the jigs and fixate the osteotomy with a LCP. After fixation with the LCP, each phantom was scanned with a laser scanner. The laser scan of the distal and proximal fragment was registered to
the preoperative plan to measure angular correction errors (ulnar deviation and flexion angles) and lengthening error.

Results: The mean errors for ulnar deviation angle, flexion angle, and lengthening were -1.0 degrees, 1.5 degrees, and 0.4 mm, respectively. The standard deviations and ranges for ulnar deviation angle, flexion angle, and lengthening were 1.8 degrees (-4.4 to 1.5 degrees), 2.6 degrees (-2.0 to 8.5 degrees), and 0.6 mm (-0.6 to 1.6 mm), respectively.

A pilot study is underway to evaluate the feasibility of the method in clinical practice. Three patients have successfully undergone DRO using the customized drill jig with freehand shaping of the distal fragment; freehand shaping was used instead of milling because we have been unable to source a Forstner bit approved for surgical applications. The results from the pilot study have been clinically acceptable with no complications.

Discussion: To achieve appropriate outcomes, care must be taken to ensure that the jigs are seated properly before drilling and shaping of the radius; clinically, this means that the exposure must be large enough to accommodate the jigs and soft tissue dissection must be complete. Also, drilling into a sloped surface can cause a drill bit to flex even with the jig and drill guide in place; marking the hole location using the jig and predrilling a pilot hole helps to minimize such errors.

A significant advantage of using customized jigs is that an intraoperative tracking system and registration is not required. The customized jigs perform the task of registration and navigational guidance in a form that is easy to use.
Upper Limb Fractures

for orthopaedic surgeons. Our results suggest that the jigs can achieve accuracy sufficient for clinical use. One disadvantage is that the preoperative plan cannot be changed intraoperatively because of the time required to fabricate and sterilize the jigs. Substantial effort and equipment are required to design and fabricate the jigs, but such services can be provided offsite of the hospital. Although a CT scan is required for surgical planning and fabrication of the jigs, no intraoperative fluoroscopy is required for navigational purposes.

References


Evaluation Of An Arthroscopic-assisted Fluoroscopic Navigation System In The Treatment Of Talar Osteochondral Lesions - A Novel Technique

O’LOUGHLIN P1, KENDOFF D2, PEARLE A3, KENNEDY JG4

Department Of Orthopedic Surgery, Hospital For Special Surgery, New York, NY, USA

oloughlinp@hss.edu

Osteochondral lesions (OCL) of the talus are a common injury especially in patients presenting with a history of ankle trauma. A recent review showed that non-operative treatment may lead to a poor outcome whereas surgical treatment was associated with excellent or good results in 85% of patients. The principle aim of surgical treatment is revascularization of the defect. This can be achieved via an anterograde or retrograde approach. An anterograde approach breaches the articular cartilage whereas a retrograde approach addresses the lesion from the subchondral bone. In those cases in which the cartilage is intact, retrograde drilling is preferred to preserve the pre-existing cartilage. The specific location of the lesion on the talar dome will affect the difficulty in targeting the lesion effectively. In particular, posteromedial and posterolateral lesions present a significant challenge when attempting to utilize a standard drill targeting device arthroscopically. This difficulty in accurately targeting the lesion using standard 2D imaging in conjunction with arthroscopy has prompted the current authors to seek more reproducible and accurate strategies. The hypothesis of the current study is that computer-navigation technology can be used to accurately identify and direct retrograde drilling of OCLs of the talus.

Traditional methods of targeting the osteochondral lesion have relied upon 2D fluoroscopic imaging with a vector guide or targeting device. This has proven to be technically challenging with questionable accuracy. In an effort to address this deficiency in targeting, the authors present a technique for 2D computer-navigated retrograde drilling of a talar OCL. This method was tested in an in vitro setting initially. The investigators subsequently used this targeting device in a patient with an OCL resulting in precise targeting and an excellent
outcome. This novel technique combines the advantages of 2D-fluoroscopic navigation and prior arthroscopic localisation to effectively target an OCL of the talus. From an orthopedic surgeon’s standpoint, the permanent navigated visualization of the drill-bit in multiple planes in relation to the target without need for additional images is an attractive prospect. A reduction in the intra-operative fluoroscopic images taken may reduce the overall morbidity for both patient and surgeon. This is made possible with the authors’ use of a visible reference point in the form of a spinal needle. This is, to the authors’ best knowledge, the first such case to be described.

The authors combined two well-established operative procedures without the necessity for great modification of either technique. The result was very promising in this first case. Post-operative MRI confirmed accurate targeting and drilling of the OCL.

While computerised navigation has proven to be an exceptional tool in targeting OCLs of the talus there are some technical concerns with this system. Cumbersome equipment and prolonged set-up time can make the procedure challenging. High cost also needs consideration. These problems will need to be addressed before this technique becomes universally acceptable. However, it does show great potential in improving clinical outcomes.

In conclusion, the authors’ have devised a technique which combines the benefits of 2D navigation technology and conventional arthroscopy of talar OCLs. This proposed technique allows accurate intra-operative targeting of the lesion without a need for repeated acquisition of images. At this stage, further prospective studies are necessary to perfect this novel technique.
Correction Off An Intra-articular Malunion Of The Distal Radius Using CT Based Preoperative Planning And Surgical Guides For Execution As An Alternative For Conventional Navigation

STOCKMANS F1, LIBBERECHT K1, VANHAECKE J1, DE SMEDT K2, GEUDENS N2, DILLE J2

1 Handgroep AZ Groeninge, Kortrijk, Belgium
2 Materialise NV, Leuven, Belgium

filip.stockmans@kuleuven-kortrijk.be

Introduction: Intra-articular malunions are difficult to treat. Articular step-offs cause arthrosis and have a negative impact on functional outcome. When they are not corrected the clinical course will inevitably lead to joint fusion or joint replacement. Intra-articular corrective osteotomies from outside to inside are difficult to perform accurately. In the radio carpal joint the arthroscopic access, the most evident solution in bigger joints, is too limited to perform the osteotomy from inside out. And even if the osteotomy is performed from outside in the osteotomy pattern is difficult to control in a completely healed fracture. The ideal osteotomy pattern and reduction sequence of the fragments requires detailed planning and are preferably as close as possible to the original fracture pattern. This fracture pattern is by nature non linear and are difficult if not impossible to reproduce by conventional cutting tools such as sagital saw blades. Navigation has been advocated in this type of procedure. However reports on the use of navigation around the wrist are very scarce and only experimental.

Materials and Methods: A 58-year-old woman sustained an intra-articular distal radius fracture initially treated with closed reduction and Kapandji pinning. During healing fracture collapse occurred resulting in pain and disability. Five
months post fracture, CT scanning showed the presence of an intraarticular malunion with 3 malunited parts and an intra articular step-off of 5 mm. The CT was used to make 3-dimensional reconstructions and simulate an optimal osteotomy pattern as a function of the previous fracture pattern and reduction planning. By using this virtual planning, a surgical guiding device for use during surgery was manufactured to perform an osteotomy with multiple drill holes along the original fracture pattern. The dept of the drilling is controlled by safety stops. The drill holes are placed to induce a structural weakening along the original fracture pattern. Typically 1.1-1.5 mm drills are used to just separate fragments, 2.0-2.5 drills are used in those places where secondary callus needs to be removed. Once all holes are drilled the final osteotomy is performed using a chisel. In this manner a highly accurate osteotomy and subsequent reduction was achieved with excellent clinical results.

Results: Post-operative CT scan showed that the average deviation with the preoperative planning was under 0.75 mm. This resulted in excellent clinical outcome. The pain and function improved rapidly and significantly. Four weeks after surgery the grip strength was already 50 % of the contra lateral wrist. At 10 weeks post-op the patient regained full mobility and function without residual pain.

Discussion: A novel technique is presented to perform a challenging procedure in a precise and reproducible fashion. In a unique collaboration between surgeons and engineers, custom-made surgical guiding devices were manufactured. With the aid of these guides the surgery can be done fast and accurately so offering a competitive alternative for conventional navigation equipment. The applicability of this technology is not limited to the distal radius. Since our first patient tree more patients could benefit from this technology to treat their malunion of the radius. One patient was treated for a combined intra and extra articular malunion of the radius and two other for a complex extra articular malunion of the radius.
Authors Index

<table>
<thead>
<tr>
<th>Authors</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abolmaesumi P</td>
<td>463</td>
</tr>
<tr>
<td>Abu-Rajab RB</td>
<td>403</td>
</tr>
<tr>
<td>Abu-Gharbieh R</td>
<td>225</td>
</tr>
<tr>
<td>Adhikari AR</td>
<td>211</td>
</tr>
<tr>
<td>Ambrosetti S</td>
<td>252</td>
</tr>
<tr>
<td>Amis A</td>
<td>341</td>
</tr>
<tr>
<td>Anglin C</td>
<td>42, 201</td>
</tr>
<tr>
<td>Anselmi L</td>
<td>323</td>
</tr>
<tr>
<td>Antonio GE</td>
<td>164</td>
</tr>
<tr>
<td>Aurakzai MK</td>
<td>211</td>
</tr>
<tr>
<td>Bae DK</td>
<td>60, 310, 406</td>
</tr>
<tr>
<td>Baines J</td>
<td>19</td>
</tr>
<tr>
<td>Bardana D</td>
<td>358</td>
</tr>
<tr>
<td>Barrett ARW</td>
<td>109</td>
</tr>
<tr>
<td>Bartl C</td>
<td>222</td>
</tr>
<tr>
<td>Basanagoudar P</td>
<td>408</td>
</tr>
<tr>
<td>Belei P</td>
<td>67, 149, 336, 456</td>
</tr>
<tr>
<td>Belvedere C</td>
<td>39, 205, 410, 416</td>
</tr>
<tr>
<td>Bhattacharyya M</td>
<td>87, 170, 413</td>
</tr>
<tr>
<td>Bianchi L</td>
<td>39, 205, 410, 416</td>
</tr>
<tr>
<td>Bisca N</td>
<td>416</td>
</tr>
<tr>
<td>Bichlmeier C</td>
<td>344</td>
</tr>
<tr>
<td>Bignozzi S</td>
<td>26, 167</td>
</tr>
<tr>
<td>Blattert T</td>
<td>157, 255</td>
</tr>
<tr>
<td>Blendeda S</td>
<td>195</td>
</tr>
<tr>
<td>Board T</td>
<td>428</td>
</tr>
<tr>
<td>Boeri C</td>
<td>29, 33, 181, 246, 423</td>
</tr>
<tr>
<td>Bohlen K</td>
<td>5</td>
</tr>
<tr>
<td>Brege C</td>
<td>213</td>
</tr>
<tr>
<td>Bretin P</td>
<td>236, 330</td>
</tr>
<tr>
<td>Briard JL</td>
<td>201</td>
</tr>
<tr>
<td>Büchler P</td>
<td>252, 257, 379</td>
</tr>
<tr>
<td>Bulstra SB</td>
<td>352</td>
</tr>
<tr>
<td>Burger J</td>
<td>252, 257</td>
</tr>
<tr>
<td>Canina M</td>
<td>323</td>
</tr>
<tr>
<td>Castillo-Cruces RA</td>
<td>327</td>
</tr>
<tr>
<td>Catani F</td>
<td>39, 205, 410, 416</td>
</tr>
<tr>
<td>Cerveri P</td>
<td>323</td>
</tr>
<tr>
<td>Chang J</td>
<td>93</td>
</tr>
<tr>
<td>Chang WS</td>
<td>60, 310, 406</td>
</tr>
<tr>
<td>Chaoui J</td>
<td>219</td>
</tr>
<tr>
<td>Cheung KW</td>
<td>134, 418</td>
</tr>
<tr>
<td>Chin PL</td>
<td>216</td>
</tr>
<tr>
<td>Chiu KH</td>
<td>134, 418</td>
</tr>
<tr>
<td>Chiu KY</td>
<td>127, 447</td>
</tr>
<tr>
<td>Cho HJ</td>
<td>406</td>
</tr>
<tr>
<td>Chong HC</td>
<td>216</td>
</tr>
<tr>
<td>Chow JC</td>
<td>192</td>
</tr>
<tr>
<td>Ciobanu E</td>
<td>29, 33, 181, 246, 423</td>
</tr>
<tr>
<td>Citak M</td>
<td>50, 115, 233, 236, 318, 330, 428</td>
</tr>
<tr>
<td>Claeys L</td>
<td>173</td>
</tr>
<tr>
<td>Clarke JV</td>
<td>16, 333</td>
</tr>
<tr>
<td>Cobb JP</td>
<td>109, 145</td>
</tr>
<tr>
<td>Confalonieri N</td>
<td>31, 71</td>
</tr>
<tr>
<td>Cui WQ</td>
<td>450</td>
</tr>
<tr>
<td>Dandachli W</td>
<td>145, 341</td>
</tr>
<tr>
<td>Dardenne G</td>
<td>219</td>
</tr>
<tr>
<td>Davies BL</td>
<td>109, 387</td>
</tr>
<tr>
<td>Davies H</td>
<td>420</td>
</tr>
<tr>
<td>Davies HG</td>
<td>22, 435, 441</td>
</tr>
<tr>
<td>Deakin AH</td>
<td>19, 213, 333, 403, 408</td>
</tr>
<tr>
<td>Decking R</td>
<td>283</td>
</tr>
<tr>
<td>Deep K</td>
<td>125</td>
</tr>
<tr>
<td>De La Fuente M</td>
<td>95, 136, 149, 189, 336, 456</td>
</tr>
<tr>
<td>De Lambilly C</td>
<td>201</td>
</tr>
<tr>
<td>De Smedt K</td>
<td>468</td>
</tr>
<tr>
<td>Diesinger Y</td>
<td>29, 33, 423</td>
</tr>
<tr>
<td>Dille J</td>
<td>468</td>
</tr>
<tr>
<td>Dillon JM</td>
<td>16</td>
</tr>
<tr>
<td>Name</td>
<td>Page(s)</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Dong X</td>
<td>262</td>
</tr>
<tr>
<td>Duda GN</td>
<td>452</td>
</tr>
<tr>
<td>Dürselen L</td>
<td>173</td>
</tr>
<tr>
<td>Echeverri S</td>
<td>262</td>
</tr>
<tr>
<td>Ecker TM</td>
<td>73</td>
</tr>
<tr>
<td>Eckman K</td>
<td>99, 192</td>
</tr>
<tr>
<td>Eid A</td>
<td>161</td>
</tr>
<tr>
<td>Elfring R</td>
<td>95, 136</td>
</tr>
<tr>
<td>Ellis RE</td>
<td>358, 463</td>
</tr>
<tr>
<td>Enomoto H</td>
<td>300, 339</td>
</tr>
<tr>
<td>Ensini A</td>
<td>39, 205, 410, 416</td>
</tr>
<tr>
<td>Eo JH</td>
<td>60</td>
</tr>
<tr>
<td>Eschweiler J</td>
<td>189</td>
</tr>
<tr>
<td>Euler E</td>
<td>344, 390</td>
</tr>
<tr>
<td>Fang LM</td>
<td>364</td>
</tr>
<tr>
<td>Faschingbauer M</td>
<td>385, 431, 433</td>
</tr>
<tr>
<td>Felciangeli A</td>
<td>39, 205, 410, 416</td>
</tr>
<tr>
<td>Feng H</td>
<td>179, 249, 347</td>
</tr>
<tr>
<td>Fichtinger G</td>
<td>81</td>
</tr>
<tr>
<td>Field RE</td>
<td>211</td>
</tr>
<tr>
<td>Fieten L</td>
<td>189</td>
</tr>
<tr>
<td>Finlay PA</td>
<td>341</td>
</tr>
<tr>
<td>Foroughi P</td>
<td>81</td>
</tr>
<tr>
<td>Franck A</td>
<td>157, 255</td>
</tr>
<tr>
<td>Friederich NF</td>
<td>84</td>
</tr>
<tr>
<td>Fu C</td>
<td>42</td>
</tr>
<tr>
<td>Fuchs S</td>
<td>431, 433</td>
</tr>
<tr>
<td>Fukui T</td>
<td>266, 285</td>
</tr>
<tr>
<td>Fukunishi S</td>
<td>266, 285</td>
</tr>
<tr>
<td>Funayama A</td>
<td>300</td>
</tr>
<tr>
<td>Gall Sims SE</td>
<td>11</td>
</tr>
<tr>
<td>Ganz R</td>
<td>64</td>
</tr>
<tr>
<td>García J</td>
<td>375</td>
</tr>
<tr>
<td>Gardner M</td>
<td>428</td>
</tr>
<tr>
<td>Gathmann S</td>
<td>185</td>
</tr>
<tr>
<td>Gaulke R</td>
<td>233</td>
</tr>
<tr>
<td>Gebhard F</td>
<td>55, 222</td>
</tr>
<tr>
<td>Gefen A</td>
<td>238</td>
</tr>
<tr>
<td>Geng X</td>
<td>179</td>
</tr>
<tr>
<td>Gerber B</td>
<td>87, 170, 413</td>
</tr>
<tr>
<td>Gerely GI</td>
<td>439</td>
</tr>
<tr>
<td>Gerlach U</td>
<td>385</td>
</tr>
<tr>
<td>Geudens N</td>
<td>468</td>
</tr>
<tr>
<td>Giannini S</td>
<td>39, 205, 410, 416</td>
</tr>
<tr>
<td>Goldberg T</td>
<td>422</td>
</tr>
<tr>
<td>Golesk P</td>
<td>57</td>
</tr>
<tr>
<td>Gomes MPSF</td>
<td>109</td>
</tr>
<tr>
<td>González Ballester MA</td>
<td>46, 375, 379</td>
</tr>
<tr>
<td>Gosling T</td>
<td>115, 318</td>
</tr>
<tr>
<td>Goutallier D</td>
<td>444</td>
</tr>
<tr>
<td>Granich C</td>
<td>130, 209</td>
</tr>
<tr>
<td>Gravius S</td>
<td>149, 189</td>
</tr>
<tr>
<td>Gregori A</td>
<td>16</td>
</tr>
<tr>
<td>Greidanus NV</td>
<td>42</td>
</tr>
<tr>
<td>Grifka J</td>
<td>198, 288</td>
</tr>
<tr>
<td>Grützner PA</td>
<td>55, 159</td>
</tr>
<tr>
<td>Guy P</td>
<td>225</td>
</tr>
<tr>
<td>Haas NP</td>
<td>243</td>
</tr>
<tr>
<td>Hacihaliloglu I</td>
<td>225</td>
</tr>
<tr>
<td>Haimerl M</td>
<td>73</td>
</tr>
<tr>
<td>Hakki S</td>
<td>14, 269, 271</td>
</tr>
<tr>
<td>Hamitouche C</td>
<td>219</td>
</tr>
<tr>
<td>Hananouchi T</td>
<td>62, 274</td>
</tr>
<tr>
<td>Hankemeier S</td>
<td>428</td>
</tr>
<tr>
<td>Harris SJ</td>
<td>109</td>
</tr>
<tr>
<td>Hasler C</td>
<td>257</td>
</tr>
<tr>
<td>Hattori A</td>
<td>312</td>
</tr>
<tr>
<td>Haug A</td>
<td>53</td>
</tr>
<tr>
<td>Hedel BP</td>
<td>109</td>
</tr>
<tr>
<td>Heining SM</td>
<td>344, 390</td>
</tr>
<tr>
<td>Helfrich C</td>
<td>84</td>
</tr>
<tr>
<td>Heller MO</td>
<td>452</td>
</tr>
<tr>
<td>Helmy N</td>
<td>42</td>
</tr>
<tr>
<td>Hirschmann MT</td>
<td>84</td>
</tr>
<tr>
<td>Hodgsong AJ</td>
<td>42, 105, 225</td>
</tr>
<tr>
<td>Name</td>
<td>Pages</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Hofbauer VR</td>
<td>243, 321</td>
</tr>
<tr>
<td>Hoffart R</td>
<td>260</td>
</tr>
<tr>
<td>Ho KCT</td>
<td>201</td>
</tr>
<tr>
<td>Hong L</td>
<td>179</td>
</tr>
<tr>
<td>Hoppe T</td>
<td>95</td>
</tr>
<tr>
<td>Huang N</td>
<td>364</td>
</tr>
<tr>
<td>Hüfner T</td>
<td>50, 55, 115, 233, 236, 318, 330, 428</td>
</tr>
<tr>
<td>Hujita Y</td>
<td>300</td>
</tr>
<tr>
<td>Hu L</td>
<td>118, 364</td>
</tr>
<tr>
<td>Hungerer S</td>
<td>53</td>
</tr>
<tr>
<td>Hungr NA</td>
<td>105</td>
</tr>
<tr>
<td>Hung TSS</td>
<td>350</td>
</tr>
<tr>
<td>Hur CI</td>
<td>454</td>
</tr>
<tr>
<td>Hur JH</td>
<td>450</td>
</tr>
<tr>
<td>Hu Y</td>
<td>249, 347</td>
</tr>
<tr>
<td>Ilyas J</td>
<td>213</td>
</tr>
<tr>
<td>Imai K</td>
<td>298</td>
</tr>
<tr>
<td>Imhoff AB</td>
<td>55</td>
</tr>
<tr>
<td>Iwana D</td>
<td>280, 307</td>
</tr>
<tr>
<td>Jakopec M</td>
<td>109</td>
</tr>
<tr>
<td>Janecek M</td>
<td>461</td>
</tr>
<tr>
<td>Jaramaz B</td>
<td>99, 111, 192, 397</td>
</tr>
<tr>
<td>Jarvers JS</td>
<td>157, 255</td>
</tr>
<tr>
<td>Jenny JY</td>
<td>29, 33, 181, 246, 423</td>
</tr>
<tr>
<td>Jiang JY</td>
<td>364</td>
</tr>
<tr>
<td>Jolles BM</td>
<td>459</td>
</tr>
<tr>
<td>Josephs L</td>
<td>8</td>
</tr>
<tr>
<td>Joskowicz L</td>
<td>238, 371</td>
</tr>
<tr>
<td>Josten C</td>
<td>157, 255</td>
</tr>
<tr>
<td>Juergens C</td>
<td>315, 385, 431, 433</td>
</tr>
<tr>
<td>Jung KY</td>
<td>310</td>
</tr>
<tr>
<td>Jutte PC</td>
<td>352</td>
</tr>
<tr>
<td>Kabir K</td>
<td>189</td>
</tr>
<tr>
<td>Kakimoto A</td>
<td>280, 307</td>
</tr>
<tr>
<td>Kalairajah Y</td>
<td>211</td>
</tr>
<tr>
<td>Kalteis T</td>
<td>198, 288</td>
</tr>
<tr>
<td>Kamat YD</td>
<td>211</td>
</tr>
<tr>
<td>Kandasami M</td>
<td>403</td>
</tr>
<tr>
<td>Kaneko H</td>
<td>300</td>
</tr>
<tr>
<td>Kannan V</td>
<td>145</td>
</tr>
<tr>
<td>Karkare N</td>
<td>130</td>
</tr>
<tr>
<td>Katscher S</td>
<td>157, 255</td>
</tr>
<tr>
<td>Kawakami H</td>
<td>312</td>
</tr>
<tr>
<td>Kendoff D</td>
<td>36, 57, 115, 130, 209, 233, 236, 318, 330, 428</td>
</tr>
<tr>
<td>Kennedy JG</td>
<td>466</td>
</tr>
<tr>
<td>Keppler P</td>
<td>55, 222</td>
</tr>
<tr>
<td>Kiefer H</td>
<td>277</td>
</tr>
<tr>
<td>Kim K</td>
<td>353</td>
</tr>
<tr>
<td>Kim TH</td>
<td>183</td>
</tr>
<tr>
<td>Kim YH</td>
<td>353</td>
</tr>
<tr>
<td>Kim YJ</td>
<td>454</td>
</tr>
<tr>
<td>Kinninmonth A</td>
<td>16, 403</td>
</tr>
<tr>
<td>Kirs G</td>
<td>356</td>
</tr>
<tr>
<td>Kitada M</td>
<td>280, 307</td>
</tr>
<tr>
<td>Klingenstein G</td>
<td>99</td>
</tr>
<tr>
<td>Koenig B</td>
<td>243</td>
</tr>
<tr>
<td>König C</td>
<td>452</td>
</tr>
<tr>
<td>Kowal J</td>
<td>50, 101, 252, 257</td>
</tr>
<tr>
<td>Koyama T</td>
<td>62</td>
</tr>
<tr>
<td>Kozak J</td>
<td>222</td>
</tr>
<tr>
<td>Kozic N</td>
<td>46</td>
</tr>
<tr>
<td>Krenn M</td>
<td>252</td>
</tr>
<tr>
<td>Krettek C</td>
<td>55, 115, 233, 236, 318, 428</td>
</tr>
<tr>
<td>Krettek M</td>
<td>330</td>
</tr>
<tr>
<td>Krüger SL</td>
<td>459</td>
</tr>
<tr>
<td>Kumar P</td>
<td>213</td>
</tr>
<tr>
<td>Kumta SM</td>
<td>164</td>
</tr>
<tr>
<td>Kunz M</td>
<td>358, 463</td>
</tr>
<tr>
<td>Kwon OM</td>
<td>139, 142</td>
</tr>
<tr>
<td>Name</td>
<td>Pages</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Kwon YS</td>
<td>183</td>
</tr>
<tr>
<td>Lampe F</td>
<td>5</td>
</tr>
<tr>
<td>Langlotz F</td>
<td>185</td>
</tr>
<tr>
<td>Laskin R</td>
<td>209</td>
</tr>
<tr>
<td>Leardini A</td>
<td>39, 205, 410</td>
</tr>
<tr>
<td>Leardini L</td>
<td>416</td>
</tr>
<tr>
<td>Le DP</td>
<td>353</td>
</tr>
<tr>
<td>Lee CT</td>
<td>139, 142</td>
</tr>
<tr>
<td>Lee HJ</td>
<td>139</td>
</tr>
<tr>
<td>Lee JS</td>
<td>142</td>
</tr>
<tr>
<td>Lee KS</td>
<td>134, 164, 176, 229</td>
</tr>
<tr>
<td>Lee MY</td>
<td>350</td>
</tr>
<tr>
<td>Lee SH</td>
<td>183</td>
</tr>
<tr>
<td>Lee ST</td>
<td>183</td>
</tr>
<tr>
<td>Leitner F</td>
<td>222</td>
</tr>
<tr>
<td>Leung KS</td>
<td>176, 229</td>
</tr>
<tr>
<td>Leyvraz PF</td>
<td>459</td>
</tr>
<tr>
<td>Libberecht K</td>
<td>468</td>
</tr>
<tr>
<td>Liebergall M</td>
<td>238, 371</td>
</tr>
<tr>
<td>Ling M</td>
<td>463</td>
</tr>
<tr>
<td>Lin H</td>
<td>361</td>
</tr>
<tr>
<td>Lippincott C</td>
<td>36</td>
</tr>
<tr>
<td>Lisy M</td>
<td>461</td>
</tr>
<tr>
<td>Liu KG</td>
<td>127</td>
</tr>
<tr>
<td>Liu WY</td>
<td>118, 249, 347, 364</td>
</tr>
<tr>
<td>Ljungqvist J</td>
<td>55</td>
</tr>
<tr>
<td>Lo D</td>
<td>57</td>
</tr>
<tr>
<td>Lo NN</td>
<td>216</td>
</tr>
<tr>
<td>Lopomo N</td>
<td>167, 323</td>
</tr>
<tr>
<td>Lo Presti M</td>
<td>26</td>
</tr>
<tr>
<td>Lorsakul A</td>
<td>368</td>
</tr>
<tr>
<td>Lutz C</td>
<td>379</td>
</tr>
<tr>
<td>Ma B</td>
<td>463</td>
</tr>
<tr>
<td>Maegerlein S</td>
<td>315, 385, 431, 433</td>
</tr>
<tr>
<td>Mahaisavariya B</td>
<td>368</td>
</tr>
<tr>
<td>Manzotti A</td>
<td>31, 71</td>
</tr>
<tr>
<td>Marcacci M</td>
<td>26, 167, 323</td>
</tr>
<tr>
<td>Authors</td>
<td>Pages</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Nishii T</td>
<td>62, 274, 280, 307</td>
</tr>
<tr>
<td>Nishio S</td>
<td>266, 285</td>
</tr>
<tr>
<td>Nodwell E</td>
<td>201</td>
</tr>
<tr>
<td>Nofrini L</td>
<td>26</td>
</tr>
<tr>
<td>Noh JH</td>
<td>60, 310, 406</td>
</tr>
<tr>
<td>Nolte LP</td>
<td>46, 159, 252, 262,</td>
</tr>
<tr>
<td>Nodwell E</td>
<td>379, 382, 394</td>
</tr>
<tr>
<td>O’Brien P</td>
<td>225</td>
</tr>
<tr>
<td>O’Loughlin P</td>
<td>36, 57, 233, 236, 330, 466</td>
</tr>
<tr>
<td>Oess NP</td>
<td>122</td>
</tr>
<tr>
<td>Oh KJ</td>
<td>183</td>
</tr>
<tr>
<td>Onstottag O</td>
<td>283</td>
</tr>
<tr>
<td>Otswald M</td>
<td>115, 233, 236, 318</td>
</tr>
<tr>
<td>Otani T</td>
<td>339</td>
</tr>
<tr>
<td>Overhoff HM</td>
<td>84</td>
</tr>
<tr>
<td>Pang HN</td>
<td>216</td>
</tr>
<tr>
<td>Park JS</td>
<td>139, 142</td>
</tr>
<tr>
<td>Park SJ</td>
<td>454</td>
</tr>
<tr>
<td>Park WM</td>
<td>353</td>
</tr>
<tr>
<td>Pearle A</td>
<td>36, 57, 130, 209, 466</td>
</tr>
<tr>
<td>Peleg E</td>
<td>238, 371</td>
</tr>
<tr>
<td>Perka C</td>
<td>452</td>
</tr>
<tr>
<td>Perumal V</td>
<td>77</td>
</tr>
<tr>
<td>Peterhans M</td>
<td>375</td>
</tr>
<tr>
<td>Pfenniger A</td>
<td>252</td>
</tr>
<tr>
<td>Piao TH</td>
<td>450</td>
</tr>
<tr>
<td>Picard F</td>
<td>16, 19, 213, 333, 403, 408</td>
</tr>
<tr>
<td>Pichora D</td>
<td>463</td>
</tr>
<tr>
<td>Pink M</td>
<td>461</td>
</tr>
<tr>
<td>Pink T</td>
<td>461</td>
</tr>
<tr>
<td>Pinzuti JB</td>
<td>222</td>
</tr>
<tr>
<td>Piotrowski W</td>
<td>252</td>
</tr>
<tr>
<td>Plaskos C</td>
<td>105, 130, 201, 209</td>
</tr>
<tr>
<td>Porthene F</td>
<td>189</td>
</tr>
<tr>
<td>Puls M</td>
<td>101</td>
</tr>
<tr>
<td>Quack E</td>
<td>95</td>
</tr>
<tr>
<td>Queitsch C</td>
<td>315</td>
</tr>
<tr>
<td>Radermacher K</td>
<td>67, 95, 136, 149, 189, 336, 456</td>
</tr>
<tr>
<td>Raschke MJ</td>
<td>243, 321</td>
</tr>
<tr>
<td>Reichel H</td>
<td>283</td>
</tr>
<tr>
<td>Reimers N</td>
<td>379</td>
</tr>
<tr>
<td>Renkawitz T</td>
<td>198, 288</td>
</tr>
<tr>
<td>Reutlinger C</td>
<td>257</td>
</tr>
<tr>
<td>Reyes M</td>
<td>46, 379</td>
</tr>
<tr>
<td>Riesner HJ</td>
<td>157, 255</td>
</tr>
<tr>
<td>Rodriguez Y Baena FM</td>
<td>109, 387</td>
</tr>
<tr>
<td>Rohling RN</td>
<td>225</td>
</tr>
<tr>
<td>Romanowski JR</td>
<td>153</td>
</tr>
<tr>
<td>Röthlisberger M</td>
<td>185</td>
</tr>
<tr>
<td>Roux C</td>
<td>201, 219</td>
</tr>
<tr>
<td>Rudan JF</td>
<td>358, 463</td>
</tr>
<tr>
<td>Rudolph T</td>
<td>50</td>
</tr>
<tr>
<td>Ruebberdt A</td>
<td>243, 321</td>
</tr>
<tr>
<td>Sadok B</td>
<td>161</td>
</tr>
<tr>
<td>Saglamer C</td>
<td>67</td>
</tr>
<tr>
<td>Sakai T</td>
<td>62, 274</td>
</tr>
<tr>
<td>Sampath SAC</td>
<td>22, 420, 435, 441</td>
</tr>
<tr>
<td>Sangster M</td>
<td>22, 441</td>
</tr>
<tr>
<td>Satoh K</td>
<td>290</td>
</tr>
<tr>
<td>Sato Y</td>
<td>62</td>
</tr>
<tr>
<td>Sauer V</td>
<td>222</td>
</tr>
<tr>
<td>Schmerwitz U</td>
<td>277</td>
</tr>
<tr>
<td>Schmidt F</td>
<td>136</td>
</tr>
<tr>
<td>Schulz AP</td>
<td>315, 385, 431, 433</td>
</tr>
<tr>
<td>Schumann S</td>
<td>382</td>
</tr>
<tr>
<td>Schwägli T</td>
<td>84</td>
</tr>
<tr>
<td>Sculco T</td>
<td>130</td>
</tr>
<tr>
<td>Seide K</td>
<td>385</td>
</tr>
<tr>
<td>Seitz A</td>
<td>173</td>
</tr>
<tr>
<td>Sendtner E</td>
<td>198, 288</td>
</tr>
<tr>
<td>Seon JK</td>
<td>454</td>
</tr>
<tr>
<td>Sharek A</td>
<td>452</td>
</tr>
<tr>
<td>Name</td>
<td>Pages</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Shin DS</td>
<td>450</td>
</tr>
<tr>
<td>Shinji H</td>
<td>79</td>
</tr>
<tr>
<td>Siebenrock KA</td>
<td>64, 101, 185, 292</td>
</tr>
<tr>
<td>Siekmann H</td>
<td>255</td>
</tr>
<tr>
<td>Siliski JM</td>
<td>8</td>
</tr>
<tr>
<td>Sinz SG</td>
<td>439</td>
</tr>
<tr>
<td>Sinz SK</td>
<td>439</td>
</tr>
<tr>
<td>Song DY</td>
<td>81</td>
</tr>
<tr>
<td>Song EK</td>
<td>454</td>
</tr>
<tr>
<td>Song S</td>
<td>111</td>
</tr>
<tr>
<td>Song SJ</td>
<td>60, 310, 406</td>
</tr>
<tr>
<td>Steppacher SD</td>
<td>64, 73, 101, 185, 292</td>
</tr>
<tr>
<td>Stewart J</td>
<td>358</td>
</tr>
<tr>
<td>Stindel E</td>
<td>201, 219</td>
</tr>
<tr>
<td>Stöckle U</td>
<td>55, 243</td>
</tr>
<tr>
<td>Stockmans F</td>
<td>468</td>
</tr>
<tr>
<td>Strake M</td>
<td>233, 236</td>
</tr>
<tr>
<td>Stübig T</td>
<td>456</td>
</tr>
<tr>
<td>Stulberg SD</td>
<td>11</td>
</tr>
<tr>
<td>Suda Y</td>
<td>300, 339</td>
</tr>
<tr>
<td>Sugano N</td>
<td>62, 274, 280, 307, 312</td>
</tr>
<tr>
<td>Sun L</td>
<td>249, 347</td>
</tr>
<tr>
<td>Suthakorn J</td>
<td>368</td>
</tr>
<tr>
<td>Su YG</td>
<td>118</td>
</tr>
<tr>
<td>Suzuki N</td>
<td>312</td>
</tr>
<tr>
<td>Swank ML</td>
<td>77, 153</td>
</tr>
<tr>
<td>Takamatsu A</td>
<td>290</td>
</tr>
<tr>
<td>Takao M</td>
<td>62, 274</td>
</tr>
<tr>
<td>Talib H</td>
<td>375</td>
</tr>
<tr>
<td>Tang N</td>
<td>176, 229</td>
</tr>
<tr>
<td>Tang WM</td>
<td>447</td>
</tr>
<tr>
<td>Tannast M</td>
<td>46, 64, 101, 185, 292, 303, 382</td>
</tr>
<tr>
<td>Taylor RH</td>
<td>81</td>
</tr>
<tr>
<td>Tenzer Y</td>
<td>387</td>
</tr>
<tr>
<td>Teske W</td>
<td>136</td>
</tr>
<tr>
<td>Thoranaghatte R</td>
<td>394</td>
</tr>
<tr>
<td>Thornberry RL</td>
<td>90, 295</td>
</tr>
<tr>
<td>Tokunaga K</td>
<td>298</td>
</tr>
<tr>
<td>Tonetti J</td>
<td>161</td>
</tr>
<tr>
<td>Toyama Y</td>
<td>300</td>
</tr>
<tr>
<td>Trabish M</td>
<td>139, 142</td>
</tr>
<tr>
<td>Traub J</td>
<td>390</td>
</tr>
<tr>
<td>Troccaz J</td>
<td>161, 195</td>
</tr>
<tr>
<td>Tse LF</td>
<td>164</td>
</tr>
<tr>
<td>Tso CY</td>
<td>418</td>
</tr>
<tr>
<td>Tsuda K</td>
<td>274</td>
</tr>
<tr>
<td>U-Thainual P</td>
<td>368</td>
</tr>
<tr>
<td>Umarani GS</td>
<td>93</td>
</tr>
<tr>
<td>Unger A</td>
<td>315</td>
</tr>
<tr>
<td>Vallootton J</td>
<td>262</td>
</tr>
<tr>
<td>Van Driessche S</td>
<td>444</td>
</tr>
<tr>
<td>Vanhaecke J</td>
<td>468</td>
</tr>
<tr>
<td>Van Overschelde J</td>
<td>161</td>
</tr>
<tr>
<td>Vasile C</td>
<td>161</td>
</tr>
<tr>
<td>Vijayan A</td>
<td>408</td>
</tr>
<tr>
<td>Visani A</td>
<td>167</td>
</tr>
<tr>
<td>Von Recum J</td>
<td>159, 173</td>
</tr>
<tr>
<td>Voon SH</td>
<td>22, 420, 435, 441</td>
</tr>
<tr>
<td>Vouaillat H</td>
<td>161</td>
</tr>
<tr>
<td>Wahl FM</td>
<td>115, 318</td>
</tr>
<tr>
<td>Wahrburg J</td>
<td>327</td>
</tr>
<tr>
<td>Waldman SD</td>
<td>358</td>
</tr>
<tr>
<td>Wang JC</td>
<td>249, 347</td>
</tr>
<tr>
<td>Wang JQ</td>
<td>118</td>
</tr>
<tr>
<td>Wang MY</td>
<td>118, 249, 347</td>
</tr>
<tr>
<td>Wang TM</td>
<td>118, 249, 347, 364</td>
</tr>
<tr>
<td>Wang X</td>
<td>179</td>
</tr>
<tr>
<td>Wang Y</td>
<td>118</td>
</tr>
<tr>
<td>Wang YW</td>
<td>249, 347, 364</td>
</tr>
<tr>
<td>Warkentine B</td>
<td>57</td>
</tr>
<tr>
<td>Watanabe K</td>
<td>298</td>
</tr>
<tr>
<td>Weil Y</td>
<td>371</td>
</tr>
<tr>
<td>Weinhandl WE</td>
<td>439</td>
</tr>
<tr>
<td>Weisse B</td>
<td>122</td>
</tr>
</tbody>
</table>
### Keyword Index

<table>
<thead>
<tr>
<th>2D-3D registration</th>
<th>303</th>
<th>Blumensaat’s line</th>
<th>170</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D- C-Arm</td>
<td>255</td>
<td>Bone conserving implants</td>
<td>105</td>
</tr>
<tr>
<td>3-D Fluoroscopy</td>
<td>233</td>
<td>Bone fracture healing</td>
<td></td>
</tr>
<tr>
<td>3D navigation</td>
<td>176</td>
<td>Bone Morphing</td>
<td>122</td>
</tr>
<tr>
<td>3D Reconstruction</td>
<td>315</td>
<td>Bone sculpting</td>
<td>105</td>
</tr>
<tr>
<td>3D Ultrasound</td>
<td>225</td>
<td>Bone tumor</td>
<td>352</td>
</tr>
<tr>
<td>Accuracy</td>
<td>55, 298, 330</td>
<td>Cadaver study/in-vitro</td>
<td>149</td>
</tr>
<tr>
<td>Accuracy in navigated THR</td>
<td>260</td>
<td>Calcaneal fracture</td>
<td>321</td>
</tr>
<tr>
<td>Acetabular cup</td>
<td>87</td>
<td>Calcaneus</td>
<td>315</td>
</tr>
<tr>
<td>Acetabular cup orientation</td>
<td>262</td>
<td>Calibration</td>
<td>219, 375</td>
</tr>
<tr>
<td>Acetabular orientation</td>
<td>195</td>
<td>Cartilage repair</td>
<td>358</td>
</tr>
<tr>
<td>Acetabular Osteotomy</td>
<td>62</td>
<td>Cervical and thoracic spine</td>
<td>255</td>
</tr>
<tr>
<td>ACL</td>
<td>167, 170, 173, 181, 246, 347</td>
<td>Clinical measurements</td>
<td>213</td>
</tr>
<tr>
<td>ACL Reconstruction</td>
<td>249</td>
<td>Clinical results</td>
<td>139, 142, 433</td>
</tr>
<tr>
<td>ACL tunnel placement</td>
<td>243</td>
<td>Closing wedge proximal</td>
<td></td>
</tr>
<tr>
<td>Active constraints</td>
<td>109</td>
<td>Tibial osteotomy</td>
<td>60</td>
</tr>
<tr>
<td>Advanced visualization</td>
<td>390</td>
<td>Columbus Knee Design</td>
<td>14</td>
</tr>
<tr>
<td>Alignment</td>
<td>447</td>
<td>Comparative study</td>
<td>101</td>
</tr>
<tr>
<td>Anterior laxity</td>
<td>181</td>
<td>Computer</td>
<td>216</td>
</tr>
<tr>
<td>Anterior pelvic plane</td>
<td>185, 283</td>
<td>Computer Aided Navigation</td>
<td>466</td>
</tr>
<tr>
<td>Anterolateral hip approach</td>
<td>271</td>
<td>Computer Aided Spine Surgery</td>
<td></td>
</tr>
<tr>
<td>Anteversion</td>
<td>87</td>
<td>Computer assisted bone tumor surgery</td>
<td>164</td>
</tr>
<tr>
<td>Anteversion of acetabular component</td>
<td>183</td>
<td>Computer Assisted Orthopaedic Surgery</td>
<td></td>
</tr>
<tr>
<td>AP Axis</td>
<td>127</td>
<td>Computer assisted surgery</td>
<td>406</td>
</tr>
<tr>
<td>APP registration</td>
<td>90</td>
<td>Computer correction</td>
<td>292</td>
</tr>
<tr>
<td>Arthroplasty</td>
<td>216</td>
<td>Computer Navigation</td>
<td>153, 211, 459</td>
</tr>
<tr>
<td>Arthroscopy</td>
<td>179, 229, 387</td>
<td>Computer-assisted</td>
<td>170</td>
</tr>
<tr>
<td>Atlas registration</td>
<td>81</td>
<td>Computer-assisted system</td>
<td>444</td>
</tr>
<tr>
<td>Augmented reality</td>
<td>344, 390</td>
<td>Computer-Integrated Surgery</td>
<td>368</td>
</tr>
<tr>
<td>Axial rotation</td>
<td>47</td>
<td>Cooperative Force Control</td>
<td>400</td>
</tr>
</tbody>
</table>
Cost savings .................................. 356
Cost-Utility Analysis ...................... 95
Cruciate Retaining Total
Knee Arthroplasty ...................... 454
CT free navigation system .......... 266
CT measurements ...................... 47
CT-based ................................ 79, 290, 307
CT-Based hip navigation ............ 274
CT-based navigation ............ 280, 300
CT-Fluoro matching ................. 298
CT-free navigated THA ............ 285
Cup inclination ....................... 283
Cup orientation ...................... 84
Custom tumor prosthesis .......... 164
Deformity .................................. 67
Design Concept .......................... 111
DHS .......................................... 341
Digitising arm ......................... 109
Discrepancy ............................ 71
Dislocation ................................ 87
Distal locking ......................... 118
Drill Assistance ....................... 318
Dynamic loading axis .............. 102
Effect of knee prosthesis
positioning on knee
kkinematics .......................... 410
Electromagnetic .................. 134, 418
Electromagnetic navigation ..... 450
Emergency care ..................... 364
Emotion .................................. 198
EM-TKA .............................. 134, 418
Endoscopy .......................... 394, 397
Ergonomics ............................ 323
evaluation study ..................... 64
evidence-based implant design . 379
Experience ............................. 420
Experiment platform ............... 249
FEM ........................................ 238
femoral cutting guide .......... 130
Femoral Neck ......................... 118
femoral rotation ..................... 439
Femoral Shaft Fracture ....... 115, 318
femoral stem ......................... 280
Femoroacetabular impingement ..... 101
Fixator .................................. 385
flexion contracture ................. 213
fluoroscopically based
fluoroscopy .......................... 149
Fluoroscopy matching .......... 300
Force-Torque-Measurement ...... 136
FOVA ....................................... 371
Fracture .............................. 315, 385
Fracture Reduction .......... 115
Full Automatic ....................... 115
Functional outcome .............. 16
Gait analysis ......................... 16, 312
Gap ....................................... 216
gap measurements ................. 209
graft force ........................... 173
Haptics .............................. 105, 387
High tibial osteomy .... 47, 55, 310,
 ........................................ 312, 428
High-Flexion ...................... 454
Hip ........................................ 64, 71, 185, 292
Hip Dysplasia ....................... 62
hip endoprosthesis ................. 459
Hip motion simulation .......... 101
hip navigation ....................... 87
Hip OP ................................... 290
Hip resurfacing ........ 145, 149, 153,
 ........................................ 456, 459
HMD ........................................ 344
Image fusion ...................... 50, 164, 176
Image matching ..................... 353
image processing .................. 397
Imageless Navigation .... 77, 93
Implant failure ...................... 122
<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>implant fitting</td>
<td>379</td>
</tr>
<tr>
<td>In Vivo</td>
<td>201</td>
</tr>
<tr>
<td>in vivo measurements</td>
<td>257</td>
</tr>
<tr>
<td>influence patella and PCL</td>
<td>209</td>
</tr>
<tr>
<td>infrared</td>
<td>134</td>
</tr>
<tr>
<td>Insertion</td>
<td>246</td>
</tr>
<tr>
<td>Insertion of Sacroiliac</td>
<td>118</td>
</tr>
<tr>
<td>Instrument</td>
<td>394</td>
</tr>
<tr>
<td>instrumented distractor</td>
<td>257</td>
</tr>
<tr>
<td>intermuscular mini-invasive</td>
<td></td>
</tr>
<tr>
<td>hip replacement</td>
<td>271</td>
</tr>
<tr>
<td>Intramedullary Nailing</td>
<td>318, 368</td>
</tr>
<tr>
<td>intraoperative</td>
<td>67</td>
</tr>
<tr>
<td>Intra-operative measurements</td>
<td>416</td>
</tr>
<tr>
<td>IR-TKA</td>
<td>134</td>
</tr>
<tr>
<td>ISO-C3D</td>
<td>371</td>
</tr>
<tr>
<td>Isometry</td>
<td>173</td>
</tr>
<tr>
<td>Joint Line</td>
<td>416, 452</td>
</tr>
<tr>
<td>Kinematic Navigation</td>
<td>201, 461</td>
</tr>
<tr>
<td>Knee</td>
<td>31, 60, 310, 406</td>
</tr>
<tr>
<td>knee arthroplasty</td>
<td>413</td>
</tr>
<tr>
<td>knee joint kinematics</td>
<td>39</td>
</tr>
<tr>
<td>Knee Kinematics</td>
<td>167, 353</td>
</tr>
<tr>
<td>knee prosthesis designs</td>
<td>39, 410</td>
</tr>
<tr>
<td>knee tensioning</td>
<td>209</td>
</tr>
<tr>
<td>Laterally elevated wedged insole</td>
<td>312</td>
</tr>
<tr>
<td>Laxity</td>
<td>167</td>
</tr>
<tr>
<td>lean navigation</td>
<td>277</td>
</tr>
<tr>
<td>learning curve</td>
<td>19, 145, 450</td>
</tr>
<tr>
<td>Leg geometrie</td>
<td>222</td>
</tr>
<tr>
<td>leg length</td>
<td>73</td>
</tr>
<tr>
<td>leg length discrepancy</td>
<td>280</td>
</tr>
<tr>
<td>level sets</td>
<td>46</td>
</tr>
<tr>
<td>Ligament balance</td>
<td>423</td>
</tr>
<tr>
<td>Ligament Balancing</td>
<td>211</td>
</tr>
<tr>
<td>limb alignment</td>
<td>428</td>
</tr>
<tr>
<td>limb length</td>
<td>77</td>
</tr>
<tr>
<td>L-M stability</td>
<td>425</td>
</tr>
<tr>
<td>Local Phase</td>
<td>225</td>
</tr>
<tr>
<td>long leg film</td>
<td>403</td>
</tr>
<tr>
<td>Lower Volume practice</td>
<td>447</td>
</tr>
<tr>
<td>malunion</td>
<td>468</td>
</tr>
<tr>
<td>mathematical</td>
<td>22</td>
</tr>
<tr>
<td>mechanical axix</td>
<td>339</td>
</tr>
<tr>
<td>metal implant</td>
<td>307</td>
</tr>
<tr>
<td>Metal-on-Metal Hip</td>
<td></td>
</tr>
<tr>
<td>Resurfacing Arthroplasty</td>
<td>461</td>
</tr>
<tr>
<td>Micron Tracker</td>
<td>347</td>
</tr>
<tr>
<td>mid-sagittal plane</td>
<td>189</td>
</tr>
<tr>
<td>mini-incision hip arthroplasty</td>
<td>271</td>
</tr>
<tr>
<td>mini-invasive</td>
<td>31</td>
</tr>
<tr>
<td>Minimal invasive</td>
<td></td>
</tr>
<tr>
<td>surgery</td>
<td>5, 33, 260</td>
</tr>
<tr>
<td>MIS</td>
<td>127, 176, 229, 285</td>
</tr>
<tr>
<td>Mosaicplasty</td>
<td>358</td>
</tr>
<tr>
<td>navigated alignment</td>
<td></td>
</tr>
<tr>
<td>measurements</td>
<td>428</td>
</tr>
<tr>
<td>Navigated knee arthroplasty</td>
<td>14, 130, 209, 425</td>
</tr>
<tr>
<td>navigated soft tissue</td>
<td></td>
</tr>
<tr>
<td>management</td>
<td>441</td>
</tr>
<tr>
<td>navigation of patellar component positioning</td>
<td></td>
</tr>
<tr>
<td>in navigated TKR</td>
<td>205</td>
</tr>
<tr>
<td>Navigation System</td>
<td>323, 310</td>
</tr>
<tr>
<td>navigational planning</td>
<td>164</td>
</tr>
<tr>
<td>NDI</td>
<td>347, 249</td>
</tr>
<tr>
<td>Needle</td>
<td>330</td>
</tr>
<tr>
<td>Neural Network</td>
<td>368</td>
</tr>
<tr>
<td>oncology</td>
<td>352</td>
</tr>
<tr>
<td>operating time</td>
<td>26, 19</td>
</tr>
<tr>
<td>orientation</td>
<td>192</td>
</tr>
<tr>
<td>OrthoPilot</td>
<td>420</td>
</tr>
</tbody>
</table>
Surface Modeling ...................... 361
Surgeon Stress-Fatigue Analysis............................... 323
Surgical Navigation ................. 161
Surgical Robot .................. 115, 318, 350, 400
surgical technique ................. 5
Surgical Tool Segmentation ......... 225
Surgical training .................... 387
SVR ........................................... 238
Tactile Guidance System .............. 36
Talus ......................................... 466
TEA ........................................... 127
technical validation ................. 333
telepresence ............................. 364
templates ............................... 243, 358
THA .................. 73, 77, 79, 81, 84, 90,
............................... 95, 99, 183, 189, 192, 262,
............... 266, 274, 277, 280, 283, 295, 298, 300, 303, 382
thoracic pedicle screw
navigation .................................. 157
Tibia fracture ........................... 122
Tibial Plateau ............................ 236
tibio-femoral and patello-
femoral joint kinematics .......... 410
TKA .................. 5, 8, 14, 16, 19, 22, 26,
............... 29, 39, 122, 127, 136, 139,
.............. 142, 201, 205, 211, 213, 339,
.............. 350, 356, 400, 403, 408, 410,
............... 416, 418, 423, 431, 433, 435,
............... 439, 441, 444, 447, 450, 452
Tracing ...................................... 249
Tracking .................................... 394
Trauma .................. 229, 364, 468
UKR ........................................ 33, 423, 109
Ultrasound .................. 219, 84, 375, 222
uncemented ............................. 435
unicomartimental ................. 31
Unicompartmental Knee
Arthroplasty ......................... 36
US navigation ......................... 81
User-Centered Design ............. 323
valgus ...................................... 22
valgus knee ............................ 408
Validity of frontal
pelvic plane .......................... 183
Varus ....................................... 420
Virtual Fluoroscopy .............. 161
Virtual Reality ..................... 361, 387
weight bearing ...................... 428
Wireless magnetoelastic
sensing .................................. 122
wrist ....................................... 468
X-ray preview ......................... 336
X-ray radiograph ..................... 382
X-rays ................................. 292
Young modulus ................. 238
zero-dose .............................. 336
To carry out an event such as CAOS would not be possible without the support and contributions by the following companies and organizations. Their help is highly appreciated.

**Grand Benefactor**
BrainLAB AG
http://www.brainlab.de/

**General Benefactors**
DePuy
http://www.depuy.com/
Stryker
http://www.stryker.com/

**Lunch Benefactor**
Biomet
http://www.biomet.com/
CAS Innovations
http://www.cas-innovations.de/

**Nametag Benefactor**
Northern Digital, Inc.
http://www.ndigital.com/

**Conference Bag Benefactor**
Ziehm Imaging
http://www.ziehm.com/

**Proceedings Benefactor**
B. Braun Aesculap
http://www.aesculap.de/

**Award Benefactors**

- **Best Clinical Podium and Best Clinical Poster Presentations**
  B. Braun Aesculap
  http://www.aesculap.de/

- **Best Technical Podium and Best Technical Poster Presentations**
  Ziehm Imaging
  http://www.ziehm.com/

- **M.E. Müller Award for Excellence in Computer Assisted Surgery**
  MEM Foundation
  http://www.fmem.unibe.ch/
Exhibitors and other Sponsors (in alphabetic order)

atracsy
B. Braun Aesculap
Claron Technology Inc.
DePuy
Materialise
NDI
OrthoMIT
Smith & Nephew
ZESS modiCAS

Axios 3D Services GmbH
BrainLAB AG
Dept. of Orthopaedics and Traumatology,
The Chinese University of Hong Kong
Informa Healthcare
NCCR Co-Me
Novartis
Siemens
Stryker
Ziehm Imaging

Workshop Sponsors (in alphabetic order)

BrainLAB
Materialise

DePuy
Stryker