CRITICIAL POSTOPERATIVE ANALYSIS OF PATIENT-SPECIFIC INSTRUMENT ASSISTED CORRECTIVE OSTEOTOMY USING 2D/3D REGISTRATION

Chun-Sing Chui MSc[1], King-Lok Liu MD[2], Lik-Hang Hung MD[2], Kwok-Sui Leung MD[1]*

[1,]*Department of Orthopaedics and Traumatology, The Chinese University of Hong Kong, Hong Kong, China, ksleung@cuhk.edu.hk

[2,] Department of Orthopaedics and Traumatology, Prince of Wales Hospital, Hong Kong, China

INTRODUCTION

The technology and the feasibility of computer aided orthopaedic surgery (including navigation and patient-specific instrument) have been widely studied and discussed in the past few years. Surgical accuracy is one of the most essential indicators of the success of the technology. However, a reliable method for postoperative assessment is still not yet well developed and adopted. Conventionally, postoperative X-rays were used for analysing the mechanical alignment and the implant position [1]. Incorrect length of a fibular fracture reduction can be measured by plain radiographs [2]. It was also found that radiographic femoral varus angle measurement was not statistically accurate in predicting anatomic femoral varus angle [3]. Besides, the implant position and the corrections were only assessed by the simple measurement by surgeon. The method is not quantified and reliable. Postoperative CT images were also widely adopted for postoperative analysis [4]. However, postoperative CT is time consuming, costly and hazardous to patient. The quality of the images for analysis is unsatisfied due to the scattering effect by the metal implant. Using the contralateral side of the bone can also induce error [5]. 2D / 3D registration method using 3D data and two 2D radiographs has been developed. Application of the technology for three dimensional knee implant models to two dimensional fluoroscopy images has been suggested [6]. This study investigated the application of 2D / 3D registration method for postoperative analysis of accuracy in corrective osteotomy by patient specific instruments, in a repeatable, reliable and quantified way making use of a set of preoperative CT scan and postoperative X-rays (AP and Lateral) in the surgical site.

MATERIALS AND METHODS

Three patients were included in this study. All were female with hypophosphatemia rickets. The mean age at the time of surgery was 21 years old (15-31). All patients were fully informed about the surgical procedures and the involved preoperative and intraoperative study. Standard antero-posterior (AP), lateral and axial radiographs were taken. Full leg standing radiographs served as part of a diagnostic protocol for patients presenting with malalignment. Two patients were treated with unilateral femoral supracondylar osteotomy while one patient was treated with bilateral femoral supracondylar and bilateral proximal tibial osteotomies. All patients underwent multi-planar corrections. Corrective angles ranged from 11° to 19°.

CT scans with ROI from pelvis to ankle was examined. CT images were analysed in the image processing and 3D design software (Mimics®). Hip centre, knee centre and ankle centre were located and the mechanical and anatomical axes were reconstructed. Osteotomy and reduction were planned and corrected according to the mechanical axis.

Patient specific instruments (PSI) with the surface matching of the lateral distal femur were designed. The PSIs were designed with osteotomy guidance and realignment jigs during surgery. The PSIs and bone models for both osteotomies were 3D printed in the Computer Aided Surgical Modeling Laboratory (CASMLab). Preoperative trial of the PSIs on the bone models was done in the laboratory.

Intraoperatively, the PSIs were positioned according to the pre-planned osteotomy sites. K-wires and external fixation pins were inserted in the holes of the PSIs as planned. The osteotomy was done according to the cutting guidance. The realignment of the limb was completed with the jigs provided by the same PSI. The osteotomies were fixed with locked plates as planned.

Postoperatively, relative positions of bone fragments were compared to the 3D surgical plan. The 3D measurements on postoperative X-rays were facilitated by manual and automatic 2D/3D registrations using the image processing and 3D design software (Mimics®). The postoperative X-ray images were aligned with the shaft fragment bone model of the osteotomy by manual registration coarsely. Contours of the shaft fragment were then constructed on the 2 X-ray images. Automatic contour-based registration was performed to register the contours of the shaft bone drawn on the X-ray images on the shaft bone model. Contours of the condylar fragments were constructed on the 2 X-ray images. Another automatic registration was performed to register the articular bone fragment on the X-ray images. The relative bone fragment position difference between the preoperative and postoperative bone models was calculated. Standing X-ray images were also taken to evaluate the mechanical alignment.

RESULTS

From the postoperative standing X-ray images, the osteotomies and the corrected alignment were completed according to the preoperative plan. The mean tibiofemoral angle of all cases was recorded -0.38˚ ± 2.72˚.

From the 2D/3D registration of postoperative X-ray images and preoperative CT images, the average residual centre of mass translational difference between preoperative plan and postoperatively measurement was 5.47mm ± 2.43mm.

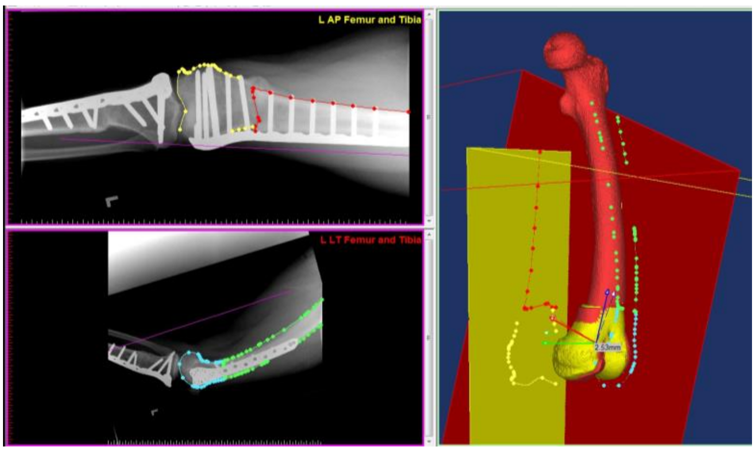

Figure 1: 2D/3D registration of postoperative X-ray images and preoperative CT images

Figure 2: Mechanical axis measurement

DISCUSSION

Comparing with a study conducted by Jung [7] on the postoperative assessment of the alignment of osteotomy round the knee using conventional surgical approach, our result is more promising. The mean TFA from Jung's study was 1 .0° ± 3.1° while the mean TFA of our study was -0.375° ± 2.72°. Comparing with the study conducted by Nazem [8] on the postoperative alignment of double tibial osteotomy using conventional surgical approach, our result is more promising as well. The mean TFA from Nazem's study was 3.93° ± 0.66° while the mean TFA of our study was 0.375° ± 2.72°. This shows that patient-specific instrument assisted corrective osteotomy can improve clinical outcome in terms of mechanical alignment.

The residual displacements in this study were 1.61±1.65 (Δx), 3.98±1.83 (Δy), and 2.34±2.3 (Δz) mm. Residual rotations were 8.08°±4.64° (Δφx), 8.87°±4.51° (Δφy), and 5.67°±1.86° (Δφz) which is comparable with Vroemen's findings (2.6±3 (Δx), 2.4±3 (Δy), and -2.2±4 (Δz) mm) [2]. Vroemen suggested the large standard deviation could be induced by persistent malalignment in individual cases. The standard deviation from our study study is much less than Vroeman's though the number of cases is less.

Although the mechanical alignment was improved by adopting patient-specific instrument, the position inaccuracy of the realigned bone fragments during intraoperative execution persisted. Few literatures are describing the intraoperative positioning accuracy using a standard, reliable and repeatable method currently while various methods were used for postoperative analysis from different studies with methods that are not reliable or repeatable. The need for using a reliable and repeatable workflow for postoperative analysis of corrective osteotomy is apparent. Our preliminary results show that the method we used is promising for postoperative assessments.

REFERENCES

- [1] Khurana D, Sankhala SS, Malik M, Shekhawat V, Rathore DS, Comparative study of high tibial osteotomy using dynamic axial fixator and locked low-profile plate in medial osteoarthritis of knee, Eur J Orthop Surg Traumatol. 2014 Dec 21.
- [2] Heineck J, Serra A, Haupt C, Rammelt S, Accuracy of corrective osteotomies in fibular malunion: a cadaver model, Foot Ankle Int. 2009 Aug;30(8):773-7.
- [3] Swiderski JK, Radecki SV, Park RD, Palmer RH, Comparison of radiographic and anatomic femoral varus angle measurements in normal dogs, Vet Surg. 2008 Jan;37(1):43-8.
- [4] Vroemen JC, Dobbe JG, Strackee SD, Streekstra GJ, Positioning evaluation of corrective osteotomy for the malunited radius: 3-D CT versus 2-D radiographs, Orthopedics. 2013 Feb; 36(2)
- [5] Kataoka T, Oka K, Miyake J, Omori S, Tanaka H, Murase T, 3-Dimensional Prebent Plate Fixation in Corrective Osteotomy of Malunited Upper Extremity Fractures Using a Real-Sized Plastic Bone Model Prepared by Preoperative Computer Simulation, J Hand Surg Am. 2013 May;38(5):909-19.
- [6] Mahfouz MR, Hoff WA, Komistek RD, Dennis DA, A robust method for registration of three-dimensional knee implant models to two-dimensional fluoroscopy images, IEEE Trans Med Imaging. 2003 Dec; 22(12):1561-74.
- [7] Jung WH, Chun CW, Lee JH, Ha JH, Kim JH, Jeong JH, Comparative study of medial opening-wedge high tibial osteotomy using 2 different implants, Arthroscopy. 2013 Jun;29 (6):1063-71.
- [8] Nazem K, Fouladi A, Chinigarzadeh M, Double tibial osteotomy for bow leg patients: A case series, J Res Med Sci. 2013 Dec;18(12):1092-6.