Non-invasive quantification of knee joint kinematics

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As Computer Assisted Orthopaedic Surgery broadens its range of application and gains support from clinical evidence, it is important to scientifically evaluate new technologies, especially their precision.

The primary aim of this study was to evaluate precision of an image free navigation system operating new software designed to provide multiple kinematic measurements of the knee. This software has been developed following the introduction of non-invasive navigation techniques which have focused on determining mechanical femoro-tibial (MFT) alignment in extension [1].

Secondary Aims

- Compare invasive and non-invasive methods of passive tracker mounting
- Compare two proposed materials for tracker base plate strapping
- Analyse the effect of flexion on measurement precision

Materials & Methods: A single investigator trained in clinical examination of the knee carried out multiple registrations on 6 knees using 4 embalmed cadaveric specimens. Age 77.8 ± 12.2 years, 2 were female. A commercially available navigation system was used with novel software. Three methods of passive tracker fixation were used including standard bone screws, a previously untested rubber strap securing a standard base plate, and a fabric strap securing the base plate. The fabric strap and base plate used have been validated previously [1].

MFT angle was recorded in neutral alignment (no applied stress), valgus stress and varus stress with the knee in extension, then at 30°, 40°, 50° and 60° of flexion. A Lachman test was performed in a manner similar to clinical practice. For each method of tracker mounting, experiment protocol was repeated 4 times on each knee, including relocation of trackers and repeat registration each time. This created 72 episodes of registration, allowing analysis of system precision and measurement repeatability within all variables.

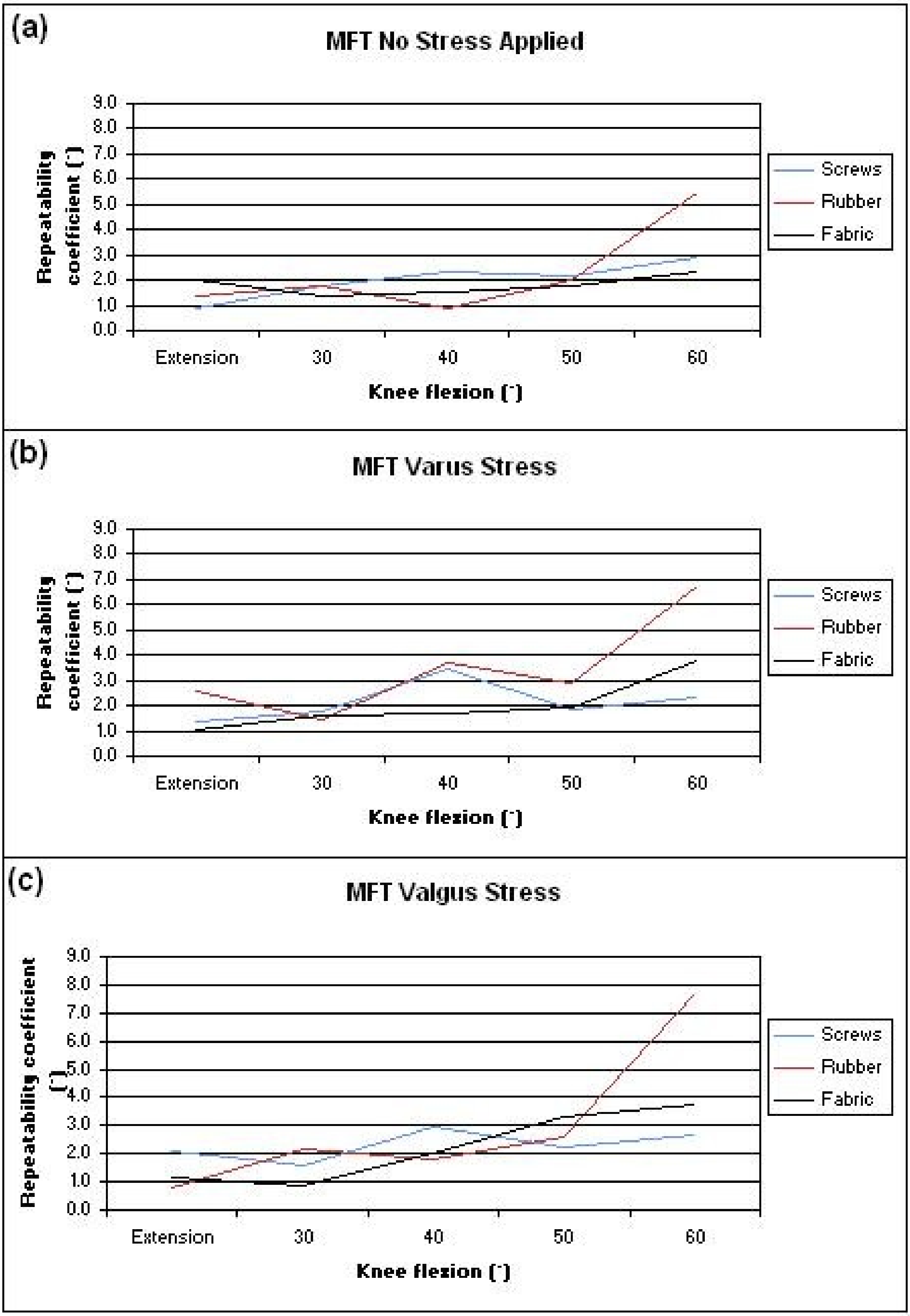
In measuring coronal alignment, the device and software manufacturer expect a precision of 1° when repeatedly measuring a fixed point. We therefore determine a repeatability coefficient of ≤2° (i.e. ± 1°), as demonstrating excellent precision. A repeatability coefficient of 3° (+/-1.5°) is within the limits of precision in the clinical setting. Regarding anterior translation of the tibia on the femur, mechanical devices such as the KT 1000 are accepted as demonstrating cruciate insufficiency if translation is ≥3mm compared to the contralateral (normal) knee during dichotomous testing [3]. We therefore accept a repeatability coefficient of ≤3mm as demonstrating precision.

Results: Each specimen exhibited a degree of fixed flexion deformity, mean 12.8° (range 6° - 20°). Table 1 demonstrates mean repeatability coefficient throughout the range of flexion tested using the 3 methods of tracker mount fixation, whilst applying the different conditions of coronal stress. Bone screw and fabric strap fixation provide superior precision compared to rubber straps in all conditions.

Table 1

	Repeatability Coefficient (°)		
Condition	Screws	Fabric	Rubber
MFT (No Stress)	2.0	1.8	2.3
Varus Stress	2.1	2.0	3.5
Valgus Stress	2.3	2.2	3.0

Graphs (a), (b) & (c) (fig.1) further convey the effect of flexion and varus/valgus stress on precision. From graph (a), precision using bone screws and fabric straps is acceptable throughout the tested range of flexion. Regarding graph (b) & (c) applying varus/valgus stress at ≥40° flexion decreases precision using all methods of tracker fixation, however fabric strap fixation remains within the limits of acceptable precision until 50° flexion.



Lachman test was performed by this investigator with the knee in slight flexion (mean 13.6°, range 7.1° – 17.6°). Table 2 demonstrates repeatability coefficient (mm) for the Lachman test using the three methods of tracker mount fixation.

Table 2

	Repeatibility Coefficient (mm)			
Flexion (°)	Screws	Fabric	Rubber	Mean
13.6	0.9	0.9	2.3	1.4

Discussion: Excellent precision was observed measuring MFT angle from 12.8° - 30° flexion using bone screws or fabric strapping of the base plate. All methods of tracker fixation demonstrated a fall off in precision beyond 30° flexion. This may be mainly attributable to soft tissue artefact when using non-invasive tracker fixation as bone pin fixation remained within accepted limits of precision in all conditions. We do not believe passive trackers should be mounted with the rubber strapping used in this study.

High levels of precision were demonstrated when measuring anterior translation of the tibia on the femur at 13.6° flexion. From the orthopaedic literature, angles of 10-30° of knee flexion are stated for performing the Lachman test. An angle of 20° flexion is generally accepted [4, 5]. Further work is required to establish precision using standardised force application at a flexion angle of 20°. A non-invasive navigation system may prove useful in the clinical setting in diagnosis of cruciate laxity, and monitoring of post-operative ligament graft integrity.

Limitations of this study include use of cadaveric specimens, in which soft tissue artefact, joint hydration and laxity differs from in vivo. Using transducers to dictate force application during coronal and sagittal stress would help standardise applied varus/valgus and anteroposterior stress.

This series of pilot experiments provided promising levels of precision in measuring knee kinematics in the coronal and sagittal planes through early flexion. The functions of this new software have many potential clinical applications including assessment of bony and soft tissue deformity, pre-operative planning, post-operative evaluation as well as pure research comparing kinematics of the normal and pathological knee.

References

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