Soft tissue motion measurement on shank and thigh with MRI

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***Abstract*—Most in vivo knee kinematic analyses are based on external markers attached to the shank and the thigh. However, the positioning of the markers and skin artifacts can affect the kinematic parameters of the bones true movement. The aim of the present study was to develop and to use a protocol and a modeling method that allows the computation of the relative motion between the bones and the markers. MRI acquisitions were performed on the right knee of eleven volunteers without knee injury. The subjects were equipped with external MRI-compatible markers and a foot drive device allowing the subjects to perform an active loaded knee extension. The bones and external markers were modeled from MRI images, a registration algorithm was applied to the bones and finally the relative motion of the thigh and shank markers with respect to their underlying bones was computed semi-automatically. As a result it has been found that the marker movement differs from the bone movement at their maxima 22 mm in translation and 15° in rotation.**

Soft tissue artifact; MRI; 3D movement

I. INTRODUCTION

In vivo joint kinematic analysis is a major tool to investigate functional activities of the knee [1]. Different systems - video, magnetic or optoelectronic - are used to capture the tibiofemoral kinematics in vivo and non-invasively. The most popular method use external markers fixed to the thigh and the shank, either with an external attachment system or directly glued to the skin. However, the question of the reliability of the kinematic parameters e.g. Euler angles [5] or helical axes [17] arose concerning these external markers [7]. Moreover the soft tissues motion between the bones and the markers is not very well known and new results in this field could alter the conclusions for motion analysis studies [2, 3, 8, 10].

During two decades the scope for Magnetic Resonance Imaging (MRI) has been constantly expanding parting from anatomical imaging to biomechanical kinematic analyses [12,14]. The MRI technology gives 3D images and presents the advantage of not being invasive for the bony structure and the soft tissues (muscles, ligament,…) surrounding it.

It has been the objective of this study to assess the 3D relative movement of a external marker sets dedicated to knee motion analysis with dynamic MRI.

II. MATERIAL & METHODS

The measurements were performed on the right knee of eleven healthy volunteers (mean age 33 years old, range 23-54, 6 males and 5 females). All the volunteers underwent a clinical knee exam performed by an orthopedic surgeon at the Polyclinique St Côme in Compiègne, and signed in an informed consent.

Inside the 1.5T Signa MRI scanner (GE Medical Systems, Milwaukee, WI, USA), the subjects were in supine position. Their ankles were fixed to a custom-made foot drive device (figure 1) manufactured with MR compatible materials.

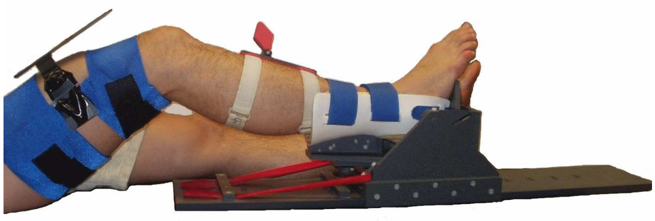

Figure 1: Foot drive device

The foot drive device was designed in order to allow a reproducible active knee movement. The subjects were equipped with an external marker set for external kinematic analyses. The femur marker set was mounted on a very light carbon composite structure and fixed to the thigh with a large neoprene band. The tibia marker set was attached to the shank, and was mounted on a PVC base attached with two Velcro bands. The thigh marker set (TMS) and shank marker set (SMS) were composed of a PVC structure equipped at each corner with four cylindrical (15mm long, 5mm in diameter) Adalat (Bayer, AG, Germany) capsules. Adalat capsules were chosen as MRI markers because of their low cost and highly visible MRI signal.

The 3D volume of the knee and the external marker sets were acquired while the subject performed a sequential and loaded knee extension. The choice of the acquisition parameters has been the result of a compromise between the total examination time and the spatial resolution. In comparison to a standard MRI knee protocol, it has been necessary to have a higher field of view and more slides in order to take into account the 3D movement of the knee.

From approximately 90° of knee flexion, the subjects performed a knee extension. During the knee extension the subjects were asked to pause three times 10 secondes until full extension. A set of notches placed on the foot drive device rail allowed the subjects to track each position. During each pause sagittal slices of anatomical structures and the shank and thigh external marker sets have been acquired with the MRI sequence FIESTA (Fast Image Employing Steady-State Acquisition). The total acquisition time per subject was 10 to 15 minutes, this time included installation of the subject and all acquisitions for the four positions.

Sagittal MRI images were then imported into a custom-made segmentation software (SIP ©INSERM, [6]) where marker sets capsules, femoral and tibial outlines for each of the four positions were detected semi-automatically. Then the outlines were imported into the PATRAN software (MSC.software, California, USA) and solid models of the bones were processed (figure 2).

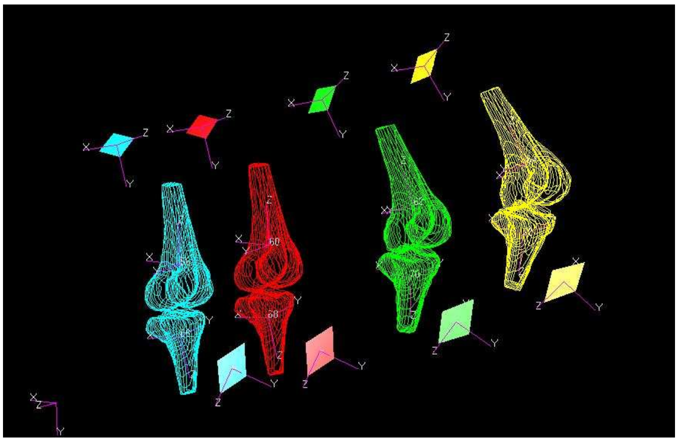

Figure 2: Solid models of Femur, tibia and markers after segmentation for different knee flexion

All femurs and tibias models were superimposed on the extension femur model and the extension tibia model. Subsequently the movement of the thigh and shank marker sets relative to the femur (figure 3) and tibia (figure 4) has been obtained. The relative movement of the marker sets has been expressed as a displacement and three rotations around reference coordinate frame axes (i.e. extension marker sets).

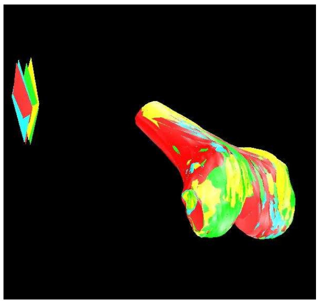

Figure 3: Shank markers after femur registrations

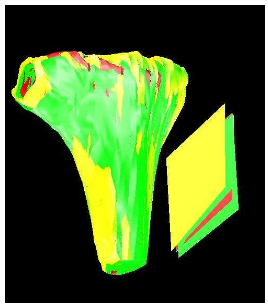

Figure 4: Thigh markers after tibia registrations

III. RESULTS

For all subjects the relative movement parameters of the thigh and shank marker sets were reported as a function of the flexion (figure 5).

The relative movement of the thigh marker sets expressed the same trend for all the subjects: an increase of the relative movement distance with the flexion angle ; linear regression between thigh marker sets distance and rotation angle (figure5).

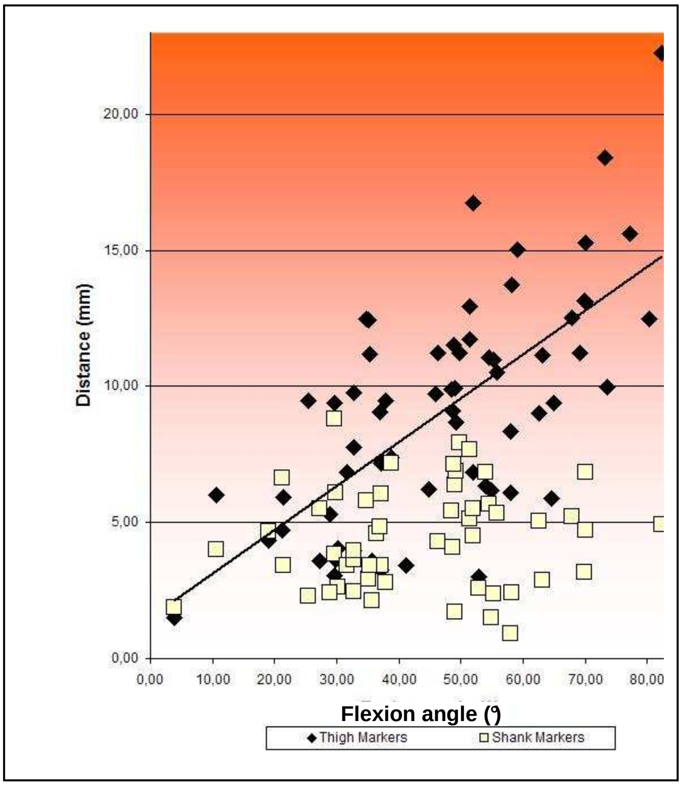

Figure 5: Markers distance vs. flexion angle

The thigh marker set distance increased from 0mm at 9° to 16mm at 90°.

The distance of the shank marker sets has been almost stable at around 4.5mm for all of the subjects (figure5). No tendency was observed for none of the subject. The relative movement rotation parameters of the thigh and shank marker sets increased with the flexion (1° to 5° for the thigh marker rotation around Z axis)

IV. DISCUSSION AND CONCLUSION

It had been the objective of the present study to develop a methodology to compare the movement of the bones and the one of the body segment external marker sets used for kinematic analyses of the knee. A MRI protocol was optimized and a modeling package has been developed.

To our knowledge only two types of techniques have been used to assess the relative movement of external marker sets versus the true movement of the bones. The first one used intra-cortical pins [4,13]or external fixtures [9]. The second one used X-Ray fluoroscopy [15, 16]. Stagni et al. (2005) gave a map of the soft tissue artefact on only two subjects. However intra-cortical pins and fluoroscopy remains invasive.

On the contrary, MRI acquisitions are fully 3D and non-invasive. However there remains the first limitation that the studied movement must stay within a small volume. The other limitation of the MRI acquisitions consists in the fact that the 3D acquisitions of the knee need to be acquired in static positions. However a finite set of positions in supine position can approximate a continuous movement[11].

The present study quantified the skin artifact for one specific external marker set. For the future, first, it would be useful to estimate the error impact of the relative motion of soft tissue on the knee kinematics parameters. Then, it would be helpful to choose and to validate a skin artifact correction method.

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