BONE SURFACE TRACKING FOR STANDING KNEE MRI: A VALIDATION STUDY

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INTRODUCTION

Accurate measurements of the relative positions of the bones in the knee are important when studying disorders and treatments of the tibiofemoral and patellofemoral joints. The strong influence of joint loading has been recognized in the development of methods to measure kinematics under physiological conditions, such as weightbearing. Joint kinematics can be tracked by registering bone surfaces between serial MRI scans (Fellows et al., 2005). The purpose of the current study was to assess the accuracy of a surface-based kinematic matching method using MRI data collected in a vertically open scanner.

METHODS

Specimen preparation: One left female cadaveric lower extremity was disarticulated at the hip and ankle and dissected of all overlying tissue to leave only the bones and passive connecting structures of the knee joint present. Nylon screws were inserted in holes that were drilled in the cortices of the femur, tibia, and patella. A hollow spherical marker covered with retro-reflective tape was glued to the head of each screw (Fig. 1A). Prior to MRI scanning, a Vicon 512 motion analysis system was used to collect the 3-D positions of each marker.
MRI scanning: Before MRI scanning, the specimen was placed into a large plastic bag which was filled with vegetable oil - a fluid selected for its MRI imaging characteristics. Sagittal scans of the specimen were acquired in the vertically open Fonar Upright 0.6T MRI. This scanner was chosen to allow for future imaging of subjects during weightbearing positions. Sampling parameters included: TE 10 ms, TR 328 ms, slice thickness 3.5 mm, matrix 416x416, FOV 300 mm, time 4:05. Two positions were measured: **Q1** – in extension, and **Q2** – after manual repositioning into approximately 10º flexion (Fig. 1B, C).

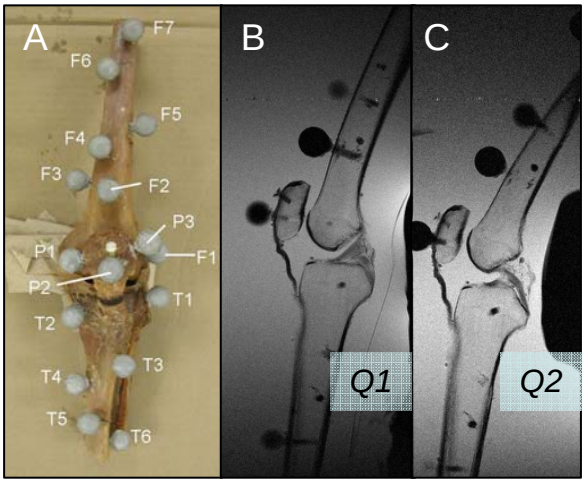

Figure 1: (A) Cadaveric knee with markers attached; (B, C) MRI images in extension *(Q1)*, and flexion *(Q2)* positions; the hollow markers appear as dark circles within the contrast fluid.

Digitization of bone and marker outlines: Images were transferred to laboratory workstations and reformatted, after which the external cortical surface of each bone and the periphery of each marker were digitized manually. The operator followed an instruction to digitize only the peripheries that could be defined with confidence. The coordinates of all digitized points were then transformed into 3-D spatial coordinates using the positional information in the scan images.

Marker based transformations: A least squares algorithm was used to fit a sphere to the points digitized on the marker outlines in the images. The distances between the computed centers of sets of markers attached to each bone were compared with those measured from the motion analysis system; the difference between those methods was found to be 0.94±0.93 mm (mean±SD). Coordinate systems were assigned based on the markers attached to each bone, and their positions were computed at Q1 and Q2. A relative transformation matrix ${}^{Q1\text{-}Q2}T_{mkr}$ between positions was calculated for each bone.

Surface based transformations: The method used to compute changes in positioning in vivo is based on matching the bone surface points in different positions. A surface fitting procedure (Hoppe et al., 1994) was first used to interpolate Q2 bone points on a 1.0 mm grid. Trimmed Iterative Closest Point matching (Chetverikov et al., 2002), a procedure that finds an optimal transformation to match a moving set of points to a target set, was used for each bone to compute the transformations ${}^{Q1\text{-}Q2}T_{TICP}$ from the moving Q1 point set to the fixed Q2 point set.

Validation comparison: We used the MRI-marker system as a comparison measure for evaluating the surface tracking method. We assigned anatomically based coordinate systems relative to landmarks digitized in the Q1 position, and we used ${}^{Q1\text{-}Q2}T_{mkr}$ and ${}^{Q1\text{-}Q2}T_{TICP}$ to calculate the positions of those systems in the Q2 position. We then calculated and compared joint displacement parameters for the tibiofemoral and patellofemoral joints at the Q2 position for a measure of the accuracy of the surface based matching in calculating joint positions.

RESULTS AND DISCUSSION

Errors were <=1.5° for all angles and <1.7 mm for all displacements (Table 1). These are similar levels of error to those found in the validation of an MRI-based method used to measure patellofemoral kinematics in supine subjects (Fellows et al., 2005). We are currently collecting these MRI data from weightbearing subjects; subjects have been able to hold this position in both symmetrical flexion and single leg stance for the imaging time used in the validation study. Minimizing subject motion is critical to maintaining accuracy, and, we have therefore worked to develop a faster scanning sequence (3 minutes).

SUMMARY/CONCLUSIONS

This method can measure knee kinematics with similar accuracy to other MRI methods, with the added advantage of allowing weightbearing scanning.

REFERENCES

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Table 1: Errors and excursions for the tibiofemoral and patellofemoral joints

Degree of freedom:	Sagittal rotation (º)	Frontal rotation (º)	Axial rotation (º)	Med/lateral (mm)	Ant/post (mm)	Superior (mm)
Tibiofemoral error/excursion:	0.65/9.8	0.51/-0.5	0.60/0.0	1.48/-0.45	0.66/-0.24	0.49/3.43
Patellofemoral error/excursion:	1.50/7.63	0.65/-1.38	0.42/-0.41	1.63/1.32	0.65/-2.05	0.72/3.47