Partial Weight Bearing Patellofemoral Kinematics Measured With MRI After Total Knee Arthroplasty

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Introduction. Because implant design, surgical technique, implant positioning, and patient-specific geometry and biomechanics can all affect the performance of total knee arthroplasty (TKA) implants after surgery, there is a need for objective, quantitative methods of evaluating in vivo kinematics of knees after TKA. Tibiofemoral kinematics after TKA have been studied extensively using two dimensional fluoroscopic analyses. However, in vivo patellofemoral kinematics after TKA are not well understood. Previous work in our laboratory provided measurements of knee kinematics after TKA using magnetic resonance imaging (MRI) at afield strength of 1.5 Tesla [1]. With 3.0 Tesla MRI systems becoming more widely available and with the advent of new imaging sequences that allow volumetric imaging at nearly isotropic resolutions, we sought to develop new imaging protocols and image analysis methods to make use of the new equipment and sequences. We tested the ability of our previously-developed fast spin echo (FSE-XL) imaging protocol and an extended echo train acquisition (XETA) protocol to obtain 3-Tesla MRI images knees of patients who underwent TKA, and we developed a new method to evaluate in vivo kinematics using images of normal knees and TKA knees.

Methods. *Imaging.* Eight patients (6 males, 2 females, age 48-70 years) who underwent TKA (6 unilateral and 2 bilateral) at our institution were recruited via physician referral, and fourteen healthy control subjects (10 male, 4 female, age 22-72 years) were recruited from the surrounding community. Four of the TKA patients received a Genesis II (Smith and Nephew Orthopedics, Inc., Memphis, TN) implant, and four received a Journey implant (Smith and Nephew). Both types of implants included an oxidized zirconium femoral component and a titanium tibial component. During MR imaging a custom loading apparatus applied a compressive load to the bottom of the foot. For control subjects a load of 125 N was applied, and for TKA patients a load of 45-125 N was applied based on patient comfort level. Images were obtained at full extension and at the greatest amount of flexion that could be achieved in the scanner bore. Sagittal images of control knees and Genesis II knees were obtained on a 1.5 Tesla system (GE Signa EchoSpeed, GE Medical Systems, Waukesha, WI) using the FSE-XL sequence, TR = 3000 ms, TE = 9.4 ms, bandwidth = 62.5 kHz, echo train length =16, slice thickness = 1.5 mm, matrix = 512 x 256,and in-plane resolution = 0.3 mm. The images were reformatted to the axial plane (in-plane pixel size = 0.3 mm, slice thickness = 1 mm) for use with the new kinematic analysis software described below. Axial images of Journey knees were obtained on a 3.0 Tesla system (GE Signa EchoSpeed). Images of the patients with Journey knees were obtained using volumetric imaging: XETA sequence, TR = 2200 ms, TE = 36 ms, bandwidth = 41.67 kHz, echo train length = 44, slice thickness = 0.7 mm, matrix = 256 x 256, in-plane resolution = 0.3 mm. Axial images of one Journey knee were obtained at 3 Tesla using the same image parameters as those used at 1.5 Tesla.

Kinematic Analysis. Images were analyzed using custom software written in MATLAB (version 7, Mathworks, Natick, MA). The tibia, femur, region of patellofemoral (PF) contact, epicondylar axis of the femur, and the patellar bone/implant interface (in TKA patients) and the patellar bone/cartilage interface (in controls) were segmented using B-splines, and an iterative closest points shape matching algorithm was used to register the femur in the flexed position to the femur in the extended position. Points defining the region of PF contact were joined with a set of triangles to calculate the patellofemoral contact area (PFCA), and the area centroid was used to define movement of the PF contact location (Fig. 1). Patellar tilt was measured as the angle between the epicondylar and patellar axes, and patellar shift was measured as the position of the midpoint of the patellar axis relative to the midpoint of the epicondylar axis.

Results. Of the four knees imaged using the XETA sequence, data sets from only two knees were usable due to artifacts precluding visualization of the PF contact region in the flexed position. The PF contact region was more visible in the FSE-XL images (Fig. 2). Thus a total of three Journey knees from two subjects were analyzed, and five Genesis II knees from four subjects were analyzed. Results are provided below (Table 1).

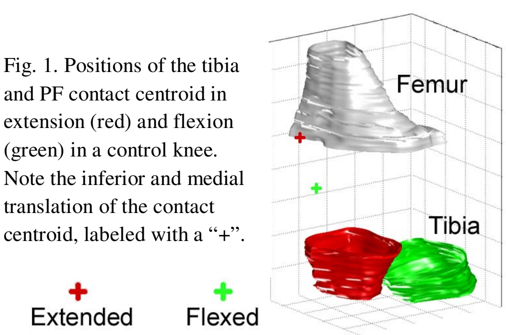

Fig. 1. Positions of the tibia and PF contact centroid in extension (red) and flexion (green) in a control knee. Note the inferior and medial translation of the contact centroid, labeled with a "+".

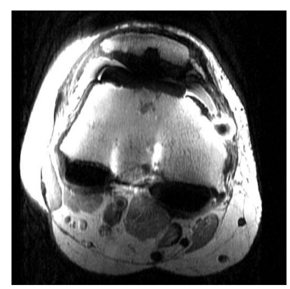

Fig. 2. Axial FSE-XL image of a TKA knee in full extension.

Table 1. Mean kinematic values ± standard deviation. Negative values indicate translations and rotations in the opposite anatomical direction.

Knee	*Knee Flexion Angle (deg)*	*Posterior PF Centroid Translation (mm)*	*Medial PF Centroid Translation (mm)*	*Inferior PF Centroid Translation (mm)*	*PFCA in Extension (mm²)*	*PFCA in Flexion (mm²)*	*Medial Patellar Tilt in Extension (deg)*	*Medial Patellar Tilt in Flexion (deg)*	*Medial Patellar Shift in Extension (mm)*	*Medial Patellar Shift in Flexion (mm)*
Genesis II (n=5)	33 ± 10	5.2 ± 5.0	-3.0 ± 17.2	31.4 ± 13.0	82.6 ± 79.9	245.7 ± 107.8	2.2 ± 5.0	5.2 ± 7.4	-0.7 ± 3.3	-3.2 ± 5.0
Journey (n = 3)	21 ± 15	4.7 ± 3.4	-4.7 ± 7.1	16.6 ± 2.0	219.7 ± 18.4	663.0 ± 131.7	8.2 ± 9.5	-1.7 ± 8.9	-1.6 ± 3.1	-3.3 ± 1.9
Controls (n=14)	40 ± 13	10.6 ± 6.4	11.8 ± 9.9	31.9 ± 9.1	267.0 ± 106.8	711.4 ± 297.1	-3.8 ± 7.7	-6.1 ± 4.2	-3.4 ± 3.4	-2.5 ±3.1

Discussion. This study provided the first measurements of in vivo knee kinematics after TKA obtained with 3-Tesla MRI. The results suggest that the FSE-XL imaging sequence is more useful than the XETA protocol for imaging of oxidized zirconium knee implants in vivo at 3 Tesla. The normative data set from the control knees can be used for comparisons with kinematics measured in TKA knees or knees with other types of injuries. The results suggest that there are important differences between the kinematics of different types of TKA implants and normal knees, but measurements of more TKA patients are needed to verify this finding.

Reference 1. Lee, K-Y et al., 2005. JMRI 21: 172-78.

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