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Femoral Condylar Contact Points Start and Remain Posterior in High Flexing Patients

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ABSTRACT

This study compares kinematic patterns of 136 patients following total knee arthroplasty with high post-operative knee flexion (*HighFlex*) versus kinematics of 114 patients with limited knee flexion (*LowFlex*) using a blocked stratified random sampling study design to reduce confounding and bias. The kinematics was collected using fluoroscopy and 2D to 3D registration for a weight-bearing deep knee bend activity. Both the lateral and the medial condylar contact positions for the *HighFlex* subjects were significantly more posterior than the *LowFlex* subjects at full extension and remained that way at all flexion angles. The amount translation of the contact points, axial orientation angle and axial rotation were found to be similar for the two groups. Lift-off was significantly higher in the LowFlex indicating mid-flexion instability.

From a patient's perspective, the success of primary total knee arthroplasty (TKA) is judged based on its ability to provide pain relief, correct deformities, and allow for a stable unhindered range of motion required for performing normal daily activities [1,2]. The excellent clinical outcomes of TKA over two decades [1–6] have encouraged surgeons to perform TKA surgeries on younger patients who have increased activity demands that require increased magnitudes of knee flexion. Moreover, ability to perform deep flexion is essential to many daily activities in both Western and non-Western cultures [7–10]. Numerous variables play a role in determining the postoperative range of motion following TKA, including preoperative (preoperative flexion, body habitus, presence of previous knee surgery [11–14]), intraoperative (ligament and gap balance, component size and position, component design, removal of osteophytes, extensor mechanism tension and balance [12,15–17]), and postoperative (postoperative rehabilitation [14], postoperative complications [18]) factors. These multiple variables likely play a role in the high variability in kinematics observed following TKA [3,19–23].

Most previous kinematic TKA studies have focused on specific designs, surgical techniques or patient population and have reported overall variation of kinematics with flexion and how it compares to the kinematics of the normal knee. Inter-subject and intra-subject variability in kinematics after TKA is often high and it remains inconclusive whether patients achieving high flexion following TKA demonstrate higher magnitudes of posterior femoral rollback (PFR) and normal axial rotation (NAR) compared to low flexing patients at the same flexion angles. The purpose of this investigation is to compare the kinematic patterns of patients with high post-operative knee flexion versus kinematics of patients with limited knee flexion at the angles of flexion common to both groups. This information could be valuable in future TKA design efforts to maximize flexion following TKA. It has been hypothesized that at full extension the location of the contact points and axial orientation angle of the femur with respect to the tibia would be similar for the two groups. However, with the onset of knee flexion, the femur of the higher flexing patients should move more posteriorly (leading to more posterior location of the contact points at all other flexion angles) and show higher amount of axial rotation (leading to higher axial orientation) with respect to the tibia when compared to patients with limited knee flexion.

Methods

Patient demographics

The data used in this study are a subset of a larger cohort of 543 subjects implanted with TKAs manufactured by Depuy, Inc. (Warsaw, IN, USA). This cohort had been collected and analyzed for kinematics, while performing an unsupported weight bearing deep knee bend (DKB) to maximum flexion without use of rails while under fluoroscopic surveillance, over the few past years across various published studies. Appropriate IRB approvals and informed consents were obtained for all the patients across all studies. The protocols of data

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collection and analysis were strictly controlled to ensure that these were consistent for all the studies. Moreover, all subjects in the study cohort needed to have well-functioning TKAs with no significant ligamentous laxity or pain, judged clinically successful (Hospital for Special Surgery scores [24] >90), and exhibit at least 110° of post-operative non-weight bearing knee flexion in order to be selected for participation. In this cohort there were six different types of TKA designs belonging to Depuy's LCS or Sigma implant systems. Based on the standard deviations observed in the cohort data, a power analysis was first conducted and a sample size of 250 was chosen because it ensured sufficient power in the study to detect differences in kinematics (90% power for detecting 1 mm of difference in distances, and 92% power for detecting 1° of difference in angles). Since different TKA designs can behave differently, the data for this study was chosen using a blocked stratified random sampling design where the percentage of patients in a stratified group for the chosen sample was the same as the percentage in the total cohort. This study design was chosen in order to restrict variability and reduce the effect of bias and confounding variables from the data. It was ensured that the selected patients fell under one of the two discrete non-overlapping groups: (1) Having maximum *weight bearing* flexion less than or equal to 95° (*LowFlex*), or (2) Having maximum *weight bearing* flexion of 110° or more (*HighFlex*). These discrete non-overlapping groups were selected so that the average maximum flexion (87.8° ± 6.7° for *LowFlex*, 119.1° ± 8.9° for *HighFlex*) in both the groups was significantly different from each other. Also, the *LowFlex* group's upper bound was chosen so that most common daily activities (67° for swing phase of gait, 83° for climbing up stairs, 90° for descending down stairs, and 93° for standing up from a chair [25,26]) were a part of this group. There were a total of 114 patients in the *LowFlex* group and a total of 136 in the *HighFlex* group. Based on PCL resection, there were 44 PCL retained (PCR), 50 PCL sacrificed (PCS; PCL removed and not replaced using a cam and post mechanism) and 156 posterior stabilized (PS) TKAs. Based on the polyethylene bearing mobility, there were 128 fixed bearing (FB), 22 AP glide (GLI) and 100 rotating platform (RP) TKAs.

2D to 3D registration

As stated before, kinematic data used in this study are a subset of data collection during previous studies. However, for the sake of completeness, the salient features of the method are highlighted. The knee joint was fluoroscoped in the sagittal plane while each patient performed a weight bearing DKB activity. The fluoroscopic video was digitized and broken down into discrete images at 30° flexion angles and in the range flexion range common to both groups (full extension (0° flexion), 30°, 60°, 90°). The three-dimensional (3D) in vivo kinematics was determined from the two-dimensional (2D) images using an automated 2D to 3D image registration technique. In this technique, 3D CAD models of implant components are fitted on the image based on their silhouette using a global optimization (simulated annealing) routine (Fig. 1). Once the correct fits are obtained, 3D kinematics (anterior–posterior position of the contact points, axial rotation and condylar lift-off) of the femoral component with respect to the tibial component is calculated based on their relative global transformation matrices [21]. The origin of the tibial coordinate system was at its geometrical center which was obtained as the intersection of the long diagonals of the bounding box enclosing the tibial model (Fig. 2). This process has a high accuracy with an error of less than 0.3 mm in anterior–posterior translation and an error of less than 0.3° in the transverse (rotational) plane [27]. In this analysis, anterior distances are denoted as positive and posterior distances are denoted as negative while externally rotated angles are treated as positive and internally rotated angles treated as negative [21].

Statistical analysis

Statistical analyses in this study were carried out on a set of 7 commonly reported variables that included 4 position/orientation variables and 3 motion (translation/rotation) variables and are outlined below:

1. LAP = Antero-posterior position of the lateral femoral condyle contact point.
2. MAP = Antero-posterior position of the medial femoral condyle contact point.
3. LTRANS = Antero-posterior translation of the lateral femoral contact points (difference of LAP) between two flexion angles.
4. MTRANS = Antero-posterior translation of the medial femoral contact points (difference of MAP) between two flexion angles.
5. ORT = Axial orientation angle of the femoral component with respect to the tibia at a flexion angle.
6. AXROT = Axial rotation of the femoral component (difference of ORT) between two flexion angles.
7. LOFF = Lift off of either femoral condyle greater than 1.0 mm.

All the variables except lift-off (LOFF) were considered as continuous variables. LOFF on the other hand was treated as a categorical variable having two possible values ‘Yes/No’ corresponding to whether there was lift off greater than 1.0 mm or not.

The data were first checked for normality using the Shapiro–Wilk test. Only when the data were found to be normally distributed, parametric tests were used. Otherwise non parametric tests were used. The data were also tested for equality of variance using the Barlett's test and Levene's test. The final selection criterion for the type of test to conduct was based both on the check for normality as well as the check for equal variance. Therefore, for all the continuous variables, the following tests were used: (1) Student's t-test (when the data were normally distributed and had equal variance); (2) Welch Anova test (when the data were normally distributed but had unequal variance); and (3) Wilcoxon Mann Whitney U-test

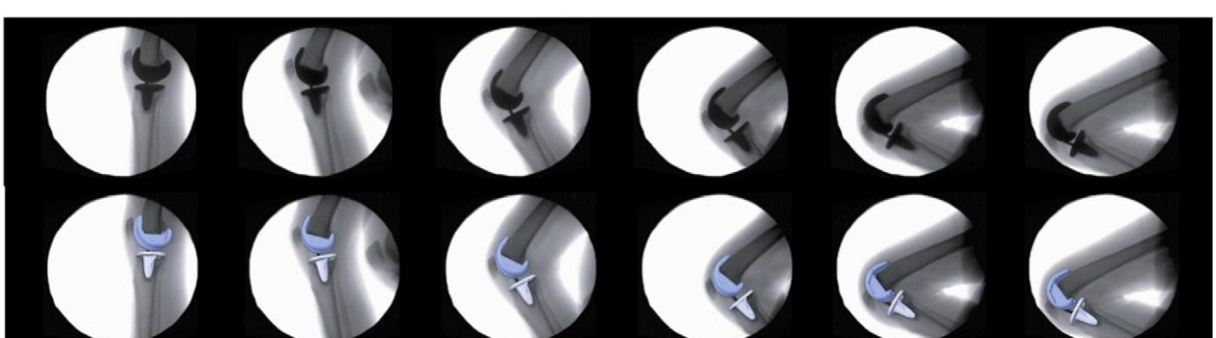

Fig. 1. A sequence of fluoroscopic images from full extension to full flexion and their corresponding overlays.