Effects of Implant Alignment on Passive Knee Envelope

+Mane, A M; ‘Maletsky, L P;
+University of Kansas, Lawrence, KS
maletsky@ku.edu

INTRODUCTION:
A successful surgical outcome in total knee arthroplasty (TKA) depends on multiple factors, including proper rotational and translational alignment of the femoral and tibial components. Small variation in surgical alignment of an implant could potentially have a large impact on knee performance. Several authors have studied the effects of tibial and femoral component’s internal-external (IE) rotational alignment on tibiofemoral kinematics; however, the variation in implant alignment and its effects on knee kinematics have not been studied. It is important to understand the relationship and interaction between various implant alignment factors and their resultant effect on post-surgery knee kinematics. The objective of the present study was to measure the effects of variation in the implant’s rotational alignment on the tibiofemoral passive envelope using principal component (PC) analysis.

METHODS:
Thirteen fresh frozen cadaver legs (Age: 67.9 yrs. ±10.1 yrs., BMI: 23.9 ± 3.7) were tested. For each leg, the femur and tibia were sectioned 22 cm proximal and 19 cm distal to the epicondylar axis. All soft tissue within 10cm of the knee joint was left intact. The tibia and femur were dissected and cemented into tubular fixtures aligned parallel to the bones’ intermediary canals. Seven different surgeons performed TKA and seven knees were implanted with a fixed posterior stabilized design and six knees were implanted with a cruciate retaining design (P.F.C. ® Fixed, DePuy Inc). After surgery, the joint was sutured and each knee underwent an envelope of motion (EOM) assessment, where the femur was fixed to a table leaving the tibia free to move (Fig. 1). Envelope assessment was performed manually by moving the tibia through the flexion-extension (FE) range of motion (ROM). As the knee was manipulated, loads and torques were applied until the tibial varus-valgus (VV) and IE rotations were constrained. Applied VV and IE torque magnitudes were within 10-15 Nm.

The tibiofemoral motion was tracked using an Optotrak 3020 system (Northern Digital Inc., Canada). Kinematics were described using a modified Grood and Sunay knee kinematics description. Medial and lateral epicondyles were identified and their locations captured using a modified stylus. Epicondylar points were later used to estimate the epicondylar width (EpW) and the frontal and transverse plane angles (FPA and TPA). Additionally, point clouds were collected on the tibial and femoral implants, which were later used to obtain following implant alignment variables: femoral and tibial IE alignments (FIE and TIE) and tibial varus and posterior slopes (TVS and TPS).

A PC models were developed for the VV and IE envelope boundaries (0°-130°), EpW, and the implant alignment variables. For each knee, the mid-point of the envelope boundaries at full extension was subtracted from the rest of the envelope to normalize the results. Models were deformed (within ±3σ) along each PC axis with all other PCs fixed at the mean, to identify the variation associated with that specific PC. Anatomical and implant alignment factors were ranked and highly ranked factors associated with first PC would be responsible for the corresponding change in the passive envelope. This PC interpretation process was continued until 85% variation in the data was explained.

RESULTS:
For the VV envelope, the first four PCs accounted for 84.8% of the total variation (Table 1). PC1 explained almost 45% of variation and was due to the change in relative position of the envelope (Fig. 2). This variation was associated with the FIE. Deformation along the PC1 axis showed that the increase in the external rotation of the femoral implant shifted the VV envelope valgus. PC2 (21.7%) explained by the varying size of the envelope, associated with the TIE and TPS (Table 1). Increase in the external alignment of tibial implant and TPS increased the envelope size. For IE envelope, four PCs accounted for 85.2% of the total variation. PC1 explained 46% of variation and was due to the envelope size (Fig. 2). This variation was tied with the TPS; increase in the TPS increased the envelope size (Fig. 2, Table 1). PC2 (22.9%) was explained by the relative position of the envelope, associated with the FIE (Table 1). PC axis deformation showed that the increase in the external rotation of femoral component shifted the IE envelope more externally, especially after 40° of knee flexion (Fig. 1).

DISCUSSION:
Two-thirds of the variation in both VV and IE envelope was captured by the first two PCs and explained by the relative position of the envelope and its size. Increase in external rotation of femoral component shifted VV and IE envelopes valgus and external respectively. Similar results were observed by Anouchi et al (CORR, 1991). The group concluded that the external rotation of femoral component decreases lateral flexion gap without creating abnormality in the medial flexion gap or abnormal stress in the lateral ligaments leading to the shift in the VV and IE knee laxity. Tibial component’s rotational alignment played crucial a role in defining envelope size. Several authors have identified the importance of TPS in increased tibiofemoral ROM. Koh et al. (JA, 2008) studied the effects of various factors on the flexion gap tightness and concluded that the tightness of the gap can be reduced by increasing the TPS. Thus, the increased VV and IE envelope size observed here could be due to the balanced flexion gap obtained with the larger TPS.

The study summarized the effects of knee implant alignment factors on the VV and IE tibiofemoral envelope. External rotation of the femoral component shifted the envelope valgus and external, whereas increase in the TPS increased the envelope size. The model will be further developed to study active motion waveforms like gait and squat.

ACKNOWLEDGEMENT:
The authors acknowledge the support of DePuy Orthopaedics, Inc.