Biomechanical Effects of Femoral Component Flexion in TKA; A Musculoskeletal Modeling Analysis

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Disclosures: M.A. Marra: None. M. Strzelczak: None. S. van de Groes: None. P.J.C. Heesterbeek: None. A.B. Wymenga: None. B. Koopman: None. D. Janssen: None. N. Verdonschot: None.

INTRODUCTION: One of the main goals in Total Knee Arthroplasty (TKA) is to restore natural knee kinematics and physiological loads in tibiofemoral (TF) and patellofemoral (PF) joint. The extent to which this is achieved may differ substantially, depending on many factors. Adding extra flexion of the femoral component (FFC) in the sagittal plane during implantation is one of these factors. More flexion may result in a more anatomical placement of the component, although its effect on the post-operative PF joint mechanics is still unknown. We hypothesize that more FFC will result in a more efficient extensor mechanism. Therefore, the aim of this study is to study the effects of varying FFC angle on the PF joint mechanics and quadriceps muscle forces.

METHODS: A previously validated patient-specific musculoskeletal model of Cruciate-Retaining (CR) TKA was used [1]. Briefly, the model included full lower extremity of the implanted side (Fig. 1a); the TF and PF joint owned 12 degrees of freedom, of which all but knee flexion/extension were solved quasi-statically, and included ligaments and rigid volume penetration to solve contact at the joint interfaces (Fig. 1b). To investigate the effect of varying FFC, we varied the FFC by 3°, 6°, 9° compared to the original (0°) post-operative alignment, leading to four cases in total. Rotation occurred around a mediolateral axis placed at the most posterior aspect of the femoral condyles (Fig. 2), in order to preserve the post-operative flexion gap. At each flexion angle, the femoral component was also raised in the proximal femur direction to preserve the post-operative extension gap.

A rise-from-a-chair activity from the existing model dataset was simulated in each case, which consisted of a rise phase followed by a sit phase. Marker trajectories were input to an inverse-kinematics analysis to compute joint angles. Subsequently, ground reaction forces and joint angles were input to an inverse-dynamics analysis coupled with Force-Dependent Kinematics to simultaneously solve muscle forces, ligament forces, joint contact forces and knee kinematics. We analyzed and compared PF contact forces, quadriceps muscle forces, and forces in the medial and lateral ligaments of the PF joint.

RESULTS: Maximum quadriceps forces decreased by 48 N, on average, for every 3° of increase of FFC at 90° of knee flexion angle (Fig. 3a). The PF contact forces followed a similar trend (Fig. 3b): they decreased by 64 N, on average, for every 3° of increase of FFC at 90° of knee flexion. On the contrary, medial and lateral PF ligaments forces increased with increasing FFC (23 N and 25 N, on average, for every 3° of increase of FFC at knee extension, respectively), although the effect was more marked when the knee was extended (Fig. 3c-d).

DISCUSSION: We showed that the FFC had an effect on the PF joint mechanics as predicted with a patient-specific model of TKA. The decrease of PF contact forces observed at higher FFC in the flexed knee position can be explained by the contemporaneous decrease of the quadriceps forces, which therefore relieves the load on the PF joint. It is speculated that a higher FFC produces an advantage for the quadriceps extensor mechanism, due to an increased moment arm. However, depending on the pre-operative situation, too high FFC may ‘over-tension’ the PF retinacula, which should be avoided. On the contrary, with a lower FFC higher quadriceps muscle forces are needed to provide the same knee extension torque, which in turn increases the PF joint contact forces.

SIGNIFICANCE: Based on this study, we concluded that adding extra FFC during TKA is advisable because it is beneficial for the quadriceps extensor mechanism and it relieves the PF joint loads. This study provides orthopedic surgeons with important indications about the effect of increased FFC, as it may potentially decrease post-operative PF joint pain and improve the knee extensor muscles function.

REFERENCES: [1] M. A. Marra, V. Vanheule, R. Fluit, B. H. F. J. M. Koopman, J. Rasmussen, N. J. J. Verdonschot, and M. S. Andersen, “A Subject-Specific Musculoskeletal Modeling Framework to Predict in Vivo Mechanics of Total Knee Arthroplasty.,” *J. Biomech. Eng.*, Nov. 2014.

ACKNOWLEDGEMENTS: This study was conducted within the ERC ‘BioMechTools’ project, funded by the European Research Council.

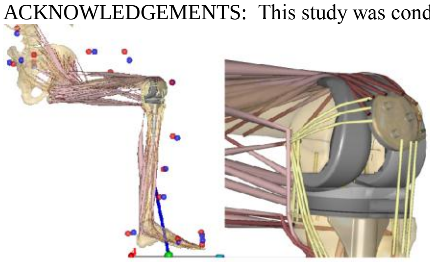

Figure 1. The musculoskeletal model of TKA.

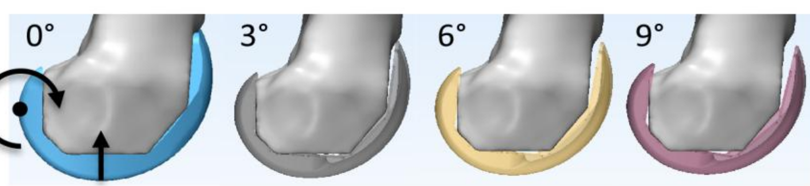

Figure 2. Model variations of the femoral component flexion angle.

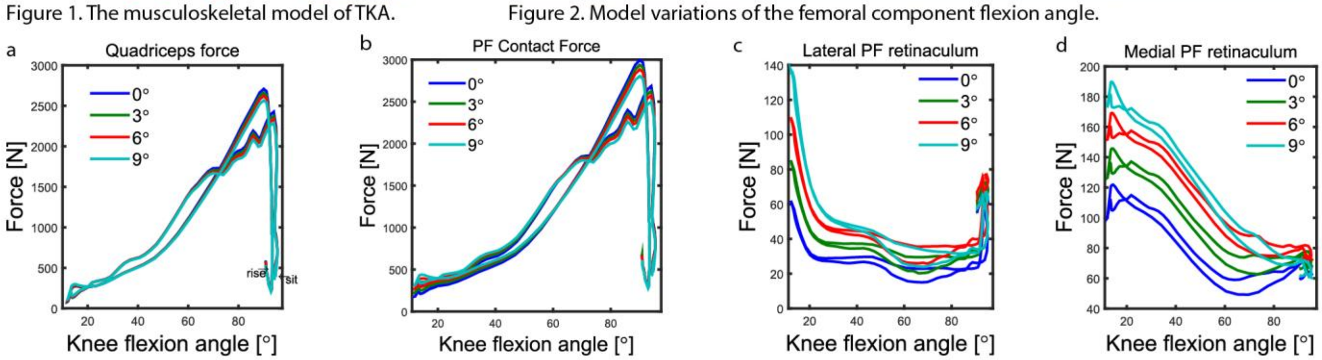

Figure 3. Quadriceps muscle forces (a), patellofemoral contact forces (b), lateral (c) and medial (d) patellofemoral ligament forces.