The Effect of Tibial Slope on the Biomechanics of Cruciate-Retaining TKA: a Musculoskeletal Simulation Study

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INTRODUCTION: Tibial slope can affect the outcomes of Total Knee Arthroplasty (TKA). More posterior slope potentially helps releasing a too tight flexion gap and it is generally associated with a wider range of post-operative knee flexion. However, the mechanism by which tibial slope affects the function of TKA during dynamic activities of daily living is rather complex and not well documented. The aim of this study was to investigate the effect of tibial slope on the kinematics of the tibiofemoral (TF) contact point, quadriceps muscle forces, and patellofemoral (PF) joint contact forces during squat. In addition, we studied the effect of anterior tibial cortex-referencing (ACR) versus center of tibial plateau-referencing (CPR), as two possible techniques to obtain the desired degree of tibial slope.

METHODS: A previously validated musculoskeletal model of a 86-year-old male subject, having a cruciate-retaining (CR) TKA prosthesis, was used to simulate a squat activity [1]. Motion-capture data were input to a motion optimization algorithm to find the full body kinematics. Quadriceps muscle forces were then calculated using inverse-dynamics. The kinematics of the TF contact point and PF joint contact forces were simultaneously calculated using force-dependent kinematics. A baseline case with 0° tibial slope was simulated, plus four additional cases with anterior (-3°), and posterior (+3°, +6°, +9°) tibial slope using the ACR technique (Fig. 1a), and four using the CPR technique (Fig. 1b).

RESULTS: Compared to the baseline, more posterior tibial slope with ACR technique resulted in a larger excursion of the TF contact point, which shifted to a more anterior position, on the lateral side, and a more posterior position, on the medial side, in extension (Fig. 2). With the CPR technique, the contact point in extension shifted gradually more posterior on both sides with more posterior slope, and in flexion it shifted gradually more posterior mainly on the lateral side. The peak quadriceps force decreased on average by 1.7 and 1.2 % BW per degree of more posterior slope, with the ACR and CPR techniques, respectively. However, due to the different relative position of patella and femur, the peak PF contact force was mainly reduced by increasing the posterior slope with the CPR technique (-3.9 % BW/degree), rather than with the ACR technique (-1.5 % BW/degree) (Fig. 3).

DISCUSSION: Increasing the tibial slope using the ACR technique produced large changes in the TF kinematics: the pattern of the contact point became more unstable, with a larger AP movement observed on the lateral side, denoting increased anterior-posterior laxity. On the other hand, variations of tibial slope with CPR technique resulted in more stable TF kinematics, more posterior position of the TF contact point, and a greater reduction of the PF contact forces. It is advisable to pre-plan the desired amount of tibial slope and execute it using the CPR technique. The surgeon should be very careful applying too much tibial slope with the ACR technique in CR-TKA, as it may have devastating effects on the TF kinematics, laxity and PF forces.

SIGNIFICANCE: This study provides new insights into the effect of variation of tibial slope in TKA using different surgical techniques, which were not documented before, and used a highly controlled and parameterized study design and dynamic loading conditions. Orthopedic surgeons can directly use these results as an indication for the clinical practice. The presented tool can also be very useful for educational/medical training purposes.

REFERENCES: [1] Marra MA, Vanheule V, Fluit R, et al. A Subject-Specific Musculoskeletal Modeling Framework to Predict In Vivo Mechanics of Total Knee Arthroplasty. ASME. *J Biomech Eng.* 2015;137(2):020904-020904-12

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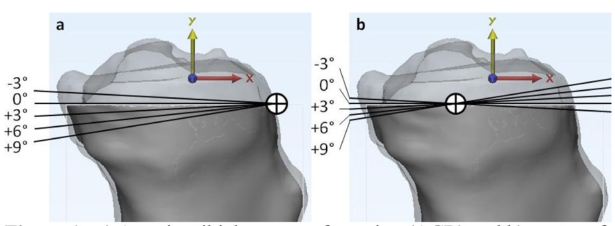

Figure 1 a) Anterior tibial cortex-referencing (ACR) and b) center of tibial plateau-referencing (CPR) techniques used to simulate varius degrees of tibial slope. Rotation centers highlighted by crossed circles.

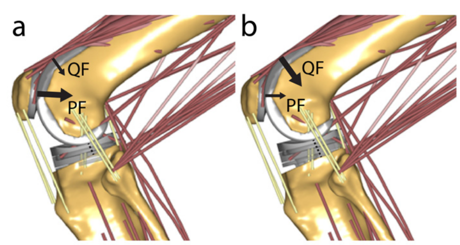

Figure 3 Conceptual representation of the quadriceps-femur (QF) and patella-femur (PF) load sharing with +9° of tibial slope with a) anterior tibial cortex (ACR) and b) center of tibial plateau (CPR) referencing techniques. The position of the patella relative to the femur is higher with ACR than with CPR. In a), due to the lower femur position (dashed lines), little quadriceps force is transmitted directly through the femur, and the PF force is higher. In b) the patella is lower and a greater quadriceps force is transmitted directly through the femur, which reduces the PF force notably.

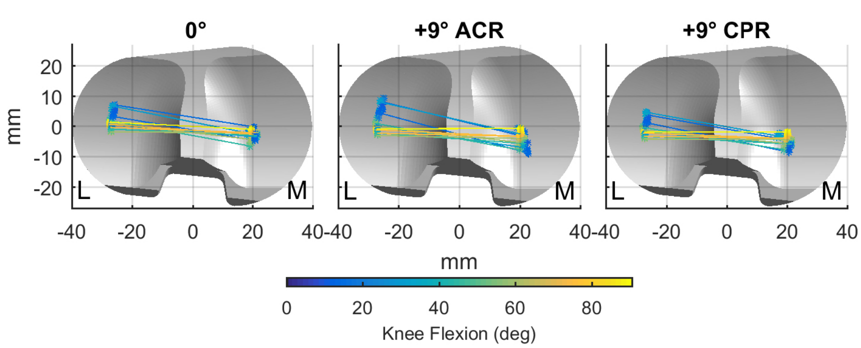

Figure 2 Kinematics of the tibiofemoral (TF) contact point during squat at baseline (0°, left), and +9° posterior slope using ACR (middle) and CPR (right) techniques. Contact points on the lateral (L) and medial (M) side of the tibial plateau are connected together and color-coded according to the knee flexion angle.