Introduction: Patient kinematics, including primary and secondary knee motions, influence the quadriceps extension mechanism at the knee. Primary kinematics (hip and knee flexion angle) and secondary kinematics (anteroposterior (AP) position of the tibia relative to the femur) change muscle length, which determines the force that can be generated. AP position of the tibia relative to the femur, and hip and knee flexion angles affect the muscle moment arm by changing the orientation of the patellar ligament and the contact point from which the moment arm is calculated. There are several reports describing motion patterns for natural knee joints and total knee replacements (TKRs) that deviate from the passive envelope of secondary knee motion. A study by Swanson et al. [1] found that anterior movement of the femur occurs at the beginning of stance for TKR patients with a posterior cruciate retaining design, after which posterior movement ensues. Because TKR patients walk differently than normal subjects, the quadriceps extension moment mechanism may also be altered for these patients. It was hypothesized that TKR patient hip and knee flexion angles will result in knee quadriceps extension moment differences for the same path of AP-tibio-femoral contact. This hypothesis was tested by using a musculoskeletal model of the knee to determine the relative influence of hip and knee flexion angles on the knee quadriceps extension moment.

Materials and Methods: To calculate quadriceps force, a musculoskeletal model of the knee was created using SIMM (Software for Musculoskeletal Modeling v4.1.1, MusculoGraphics Inc., Chicago, IL). Muscle force calculation is based on a Hill type muscle model, where the force is dependent on muscle length, pennation angle, physiologic cross-sectional area, tendon slack length, and muscle optimal-fiber length. The quadriceps complex was modeled as four discrete muscles: rectus femoris, vastus lateralis, vastus intermedialis, and vastus medialis. The musculoskeletal model was modified from that reported by Delp et al. [2]. Maximum muscle activation was assumed. Hip flexion angle, knee flexion angle, and AP translation of the tibia were applied to the model. AP-tibio-femoral contact was representative of the average of ten patients with TKRs [1]. The effect of hip and knee flexion angles on quadriceps extension moment was investigated by varying the angles over the total range of motion measured for ten TKR patients studied using gait analysis [3]. This range of motion was 21 degrees extension to 23 degrees flexion for the hip, and 8 degrees extension to 78 degrees flexion for the knee. The quadriceps extension moment was also calculated for the average TKR patient hip and knee flexion angles during the stance phase of level walking. Matlab (Matlab v6.5, The MathWorks, Inc., Natick, MA) was used to calculate AP displacement of the tibia and the quadriceps moment. AP displacement of the tibia was calculated by fitting a curve to a TKR in a sagittal plane, and calculating the translations of the tibia that resulted in the correct tibio-femoral point of contact between the tibial plateau and the TKR curve. Quadriceps moment arm was defined as the perpendicular distance from the contact point on the tibia to the patellar ligament. The muscle force outputted from SIMM for all four quadriceps muscles was summed and multiplied by the calculated moment arm to obtain quadriceps moment.

Results: The quadriceps extension moment increased by 224 Nm over the entire range of hip and knee flexion angles (Figure 1). The smallest quadriceps extension moment (37 Nm) occurred at the smallest knee flexion angle and largest hip flexion angle. The maximum quadriceps extension moment (261 Nm) occurred with the largest knee flexion angle and smallest hip flexion angle. The extension moment was more sensitive to variation in knee flexion angle, as opposed to hip flexion angle. The quadriceps extension moment was especially sensitive to knee flexion angles less than 15 degrees; approximately 84% of the 224 Nm change in quadriceps extension moment occurred for knee flexion angles between 8 degrees extension and 15 degrees flexion.

Discussion: The quadriceps extension moment increased by 6 times over the entire range of hip and knee flexion angles for ten TKR patients. Quadriceps extension moment was especially influenced by knee flexion angle. A higher knee flexion angle will increase the length of all four quadriceps muscles, increasing the amount of force generated. Changing the hip flexion angle only affects the length of the rectus femoris muscle, and has a smaller contribution to the change in quadriceps force. Gait analysis of TKR patients has shown that they have higher flexion angles during stance than their normal counterparts [3]. The results of this study show that knee flexion angles less than 15 degrees have the largest influence on quadriceps extension moment, therefore TKR patients may not reach full knee extension during stance so that they can produce a larger quadriceps extension moment.


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Figure 1. Quadriceps extension moment for the entire range of hip and knee flexion angles for ten TKR patients. The black line shows the quadriceps extension moment for the average hip and knee flexion angles for the ten patients during the stance phase of level walking.