Introduction: The degree of sagittal slope of the tibial components of total knee implants varies greatly, depending on implant design, surgical skill, problems with instrumentation, patient anatomy and surgical opinion. In this paper the effect of varying the posterior slope of the tibial components on the kinematics of fixed-bearing cruciate-retaining total knee arthroplasty was studied during simulated deep knee bending, using a computational biomechanical model.

Materials and Methods: A virtual knee simulator (LifeMOD/KneeSIM, Biomechanics Research Group, Inc., San Clemente, CA) was used to simulate deep knee bending in a manner similar to the "Purdue Knee Simulator" [1]. The virtual knee simulator is based on the multibody dynamics theory where all implants and bones are assumed rigid. The model includes tibio-femoral and patello-femoral contact, passive soft tissue, and active quadriceps and hamstring elements. The PCL, LCL and anterior and posterior bands of MCL, as well as the capsular tissues, were modeled as linear springs and the patellar tendon allowed for wrapping around implants. Flexion/extension at the hip and ankle joints, and abduction/adduction, varus/valgus and axial rotation at the ankle joint were unconstrained while a constant vertical load of 463 N was applied at the hip joint. A closed-loop controller applied tension to the quadriceps and hamstring muscles to match a prescribed knee flexion-extension profile. The components of a fixed-bearing cruciate-retaining total knee system (PFC Sigma CVD, DePuy, Warsaw, IN) were imported into the model and subjected to two cycles of deep knee bending up to 120 degrees of flexion (0 – 120 – 0 deg.). The system was analyzed with the tibial component placed at 0, 3 and 6 degrees of posterior and 3 degrees of anterior slope in the sagittal plane to represent the variation in surgical placement [2]. The antero-posterior positions of the two condylar points on the femoral lateral and medial condyles closest to the tibial tray were recorded relative to the dwell points [3]. The most posterior positions of these lowest condylar points, their AP positions at 120 deg of flexion, and the flexion angle at which posterior translation ceased were analyzed as a function of the degree of posterior tilt of the insert (+3, 0, -3, -6 deg), using least squares regression analyses.

Results: Posterior translation (rollback) of the lowest condylar points began at 0 deg of flexion and ended at between 30 and 40 degrees of knee flexion, depending on the sagittal slope of the tibial component. After the lateral lowest femoral condyle point stopped translating posteriorly, it remained in its posterior position until 60-80 degrees of flexion, before translating anteriorly by less than 2 mm. After the medial lowest femoral condyle point stopped translating posteriorly it translated anteriorly in a nearly linearly fashion until reaching the dwell point or passing anterior to the dwell point by 3 mm or less, depending on the posterior slope of the tibial component. The knee flexion angle at which anterior translation stopped was linearly related to the degree of posterior slope of the tibial insert. For every degree of increase in posterior slope, there was an advancement of one degree in the flexion angle at which posterior translation stopped (R = 0.99, p < 0.0001). The maximum posterior position reached by either lateral or medial condyles was linearly related to the posterior slope of the tibial component. There was a 1 mm increase in the maximum posterior position for every 4 degrees increase of posterior slope (R = 0.99, p < 0.1). The most posterior positions of the lateral and medial condylar lowest points were attained at a 6-deg posterior slope and were more than 11 mm from the posterior margin of the tibial insert. The antero-posterior condylar positions at the greatest flexion angle (120 deg) were also linearly related to the degree of posterior slope of the tibial component for both the lateral and medial condyles (R = 0.99, p < 0.01). At 120 deg of flexion the lateral and medial condyle AP positions were moved 1 mm posteriorly for every 5.5 deg and 4 deg (respectively) increase in the posterior slope of the tibial component.

Discussion: Since tibial component loosening continues to be one of the more common failure modes, some surgeons have proposed making the tibial cut parallel to the original slope of the tibial plateaus so that the compressive forces through the implant will be along the direction of the trabecular alignment in the proximal tibia. However, the natural slope of the tibial plateau varies by as much as from 2 to 19 deg (medial) and 1 to 13 deg (lateral) between patients [4]. The influence of such slopes on the kinematics and kinetics of the knee in activities of daily living is not well understood and there is a concern that with PCL tensioning the femur could translate too far posteriorly on the tibial implant, if the posterior slope is too great. A previous clinical study of a fixed-bearing cruciate-retaining implant (OPTETRAK, Exactech, Gainesville, FL), demonstrated that during chair-rising-sitting activities the maximum posterior position of the lowest lateral condyle point was correlated with the post-operative posterior slope (R = 0.5, p = 0.04) [3]. Thus, the computational model predicted kinematic behavior that agrees with clinical findings of similar implants and activities. In the present model of deep knee bending a posterior slope of up to 6 deg improved the posterior rollback by at most 2.5 mm, and extended the flexion angle over which posterior rollback occurred by 10 deg, without risk of causing the lowest points of the condyles to move too far posterior.