Total Knee Arthroplasty Kinematics May Be Assessed Using Computer Modeling: A Feasibility Study

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The next generational leap in computer navigation will hopefully aid surgeons in personalizing surgical techniques to patients’ individual anatomical variables to optimize outcomes. To effectively use the information obtained in the operating room, a multitude of kinematic variables must be conveyed to the orthopedic surgeon in a usable and coherent manner. This study used an intraoperative navigation system to record passive knee kinematics after a total knee arthroplasty performed. The clinical measures were taken via research software with the ability to record kinematic data in 10-second intervals.

The data from 10 consecutive clinical cases were averaged, and the translation (anterior/posterior) and rotation (internal/external) were recorded and compared from 0° to 100° of flexion to allow for comparison with the previously recorded computer model. Model and clinical curves compared favorably, with less than 1° rotational and 1.5-mm differences, on average.

The comparison of information and analyses were reviewed to indicate how they might be interpreted in the operating room for future use during surgery to allow a more personalized approach to improving functional outcomes after total knee arthroplasty.
Primary total knee arthroplasty (TKA) procedures are being performed in the United States at an exponential rate. The continued increase in health care expenditures makes it necessary to critically evaluate surgical procedures and their outcomes with regard to TKA. If the number of primary TKAs continues to increase, the number of revision surgeries will also increase in the coming years. This is evident in the fact that revision TKA has seen the highest percentage increase in the past few years compared with any other type of arthroplasty surgery. The cost of revision surgery is far greater than that of a primary procedure, and surgeons must critically evaluate how surgical technique affects function and satisfaction after TKA on a cost-effective basis. Reports in the literature have suggested that the targets orthopedists typically use for recreating the mechanical axis alignment are not always correlated with the longevity or survivorship of the procedure.

The leading causes for revision surgery are infection, aseptic loosening, instability, and polyethylene wear. The last 3 causes are believed to be associated with altered biomechanics, kinematics, and kinetics, which, combined with the fact that approximately 10% to 20% of primary TKAs lead to outcomes that do not meet patients’ satisfaction, should cause concern that the traditional targets used for TKA implants may need to be investigated and changed on an individualized basis.

Component malalignment may be one of the causes of unsatisfactory outcomes leading to TKA revision. Proper rotational alignment of the femoral component is critical, and femoral component malalignment in the transverse plane has been reported to occur in 10% to 30% of patients. Although it is not known why some patients with femoral component rotational malalignment become symptomatic and require revision surgery and some do not, it is known that computer navigational techniques do not give surgeons a functional positioning algorithm and that the anatomical landmarks do not always allow for reproducible alignment in the transverse plane.

Computer models have been used to demonstrate that variable surgical positioning of the femoral and tibial components may be a reason that fluorokinematic studies have reported significant variations between patients.

The current study was performed to determine whether computer-assisted techniques and a previously reported computer model could predict intraoperative kinematics. The transverse plane alignment of the femoral component has been variable and difficult to determine in the operating room and on 3-dimensional computed tomography scans. The current model was used to vary the internal and external rotational positioning of the femoral and tibial components to compare the average contact patterns resulting from the intraoperative navigation algorithm and the computer model. This type of information can aid surgeons in placing components with a more personalized approach rather than using absolute alignment measures, which traditionally yield an 80% patient satisfaction rate.

**Materials and Methods**

**Computer Model**

The model and method compared with the clinical data gathered in the current study has been previously reported. A virtual knee simulator (LifeMOD/ KneeSIM; LifeModeler, Inc, San Clemente, California) based on multibody dynamics was used to simulate a lunge from 0° to 100° flexion. The model included tibiofemoral and patellofemoral contact, passive soft tissues (medial, lateral, and posterior cruciate ligaments, as well as the capsular tissues), and active muscle elements (quadriceps and hamstrings) (Figure 1). All of the soft tissue attachments were taken from the registration data collected during the computer-navigated TKAs. Parasolid models of a fixed-bearing, cruciate-retaining total knee system (Columbus; B. Braun Aesculap, Tuttingen, Germany) were imported into the model, and the same implant was used throughout the clinical series.

The modeled systems were subjected to one 60-second lunge maneuver cycle (0°–100°–0° flexion). The anteroposterior (AP) positions of the lowest points on the femoral lateral and medial condyles closest to the tibial tray (the same measure used in fluoroscopy studies) were recorded relative to the dwell points for each of the inserts. The different combined trans-
placed according to the epicondylar axis and the medial third of the tibia tubercle. The ankle was free to AP translation and abduction/adduction and was given internal/external rotational stiffness and damping properties derived from the literature.\textsuperscript{17} Flexion/extension was constrained at the ankle.

The resulting contact points on the medial and lateral aspect of the tibia were then plotted and averaged by using the position of the mid-portion of the femoral component intercondylar region (Figure 2). This allowed for better comparison with the kinematics as reported in the intraoperative calculated clinical kinematics. The internal/external rotations of the model variations were plotted and averaged every 10° from 0° to 100° of flexion, and the average was used to make comparisons with the clinical data.

**Clinical Data**

Ten consecutive navigated TKAs using the Columbus cruciate-retaining total knee system were reviewed. The surgical procedures were performed using soft tissue balancing algorithms with a tibia first cut and gaps balanced to aid in femoral component positioning. After the surgical procedure was completed, the knee was passively moved from full extension to 120° of flexion over a 45- to 60-second interval. The extension/flexion path was then recorded in 10° increments from 0° to 100° of flexion for comparison with the computer model. The kinematic data were recorded using research-developed software that is not available on the standard navigation platform (OrthoPilot; B. Braun Aesculap) (Figure 3). The rotation in the transverse plane was recorded by tracking the average knee axis to the frontal plane. The anterior/posterior translation was calculated as the change in the perpendicular from the average knee center as it intersects the sagittal mechanical axis of the femur projected onto the plane of the tibial resection along the tibial AP axis (Figure 2).

**RESULTS**

The clinical and computer model results for anterior/posterior translation (Figure 4) and transverse plane rotation changes (Figure 5) were averaged at 10° intervals from 0° to 100° of flexion. The translational curves showed similar trends. The model predicted a forward translation pattern of the femur on the tibia that initiates at 40° of flexion, where clinically this started to occur at 60° of flexion. The clinical data and the model continued forward translational patterns of the femur on the tibia, with the clinical data showing more anterior translation at 100° of flexion (1.5 mm). The rotation averages for the clinical cases and the model variations showed similar ranges of internal rotation with flexion. The overall amount of rotation from extension to flexion for both averaged approximately 1.8°.

**DISCUSSION**

Since the introduction of the total condylar knee replacement, no significant technological advancement has occurred in the field of TKA. Despite the advancement of technology, variations of the same designs and materials have continued to be used over the past 30 years, as well as similar targets in which surgeons aim to implant the components during surgery. The current study shows how computer
One issue may be that the model did not include specifics about soft tissue balancing has been established. The knee may be correlated when proper design and resulting kinematic patterns of these results may indicate that the implant constraint has a larger influence on a well-balanced knee than outside muscle forces. The authors have used other implants with their computer model that show differences in rotation and AP translational patterns with variation in transverse plane implant alignments that seem to also explain the reported variations in fluorokinematic studies. One issue may be that passive open chain maneuvers in the operating room may not correlate with the lunge maneuver that was used in the computer model. It could be that implant design and constraint has a larger influence on a well-balanced knee than outside muscle forces. This is a next step of validation.

**Conclusion**

The authors have made comparisons of kinematic profiles of navigated TKAs that seemed to correlate with the patterns of AP translation and internal/external rotational patterns of a computer model. The available technology is increasing at an exponential rate, and hopefully these leaps in technology can be translated into the operating room to give surgeons more powerful tools to assure good, long-lasting functional outcomes after TKA.

**References**


