ATTUNE™ Knee System

Improving Dynamic Mid-stance Stability: An Experimental and Finite Element Study

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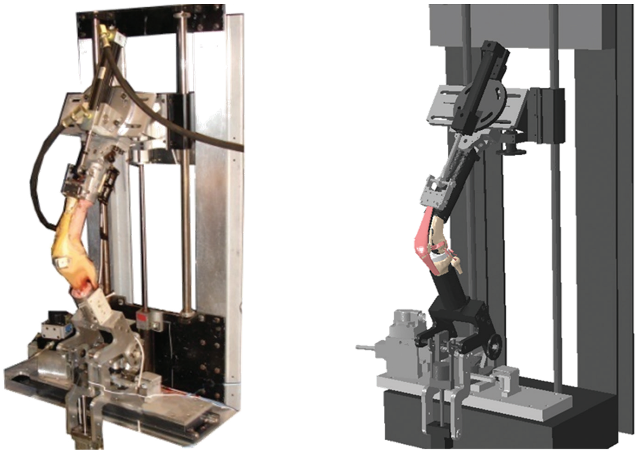
Introduction

Fluoroscopic kinematic evaluation of total knee arthroplasty (TKA) has shown a sudden anterior shift of the tibiofemoral contact point, frequently of the medial femoral condyle[1]. It has been suggested this motion is tied to abrupt changes in the femoral sagittal radius of curvature (J-Curve) typical of traditional TKA. To evaluate the link between detailed implant geometry and joint mechanics, an experimental or computational model that effectively demonstrates the in vivo behavior is a necessity.

The purpose of the current study was to utilize a previously validated computational model of the Kansas knee simulator (KKS)[2] to understand the influence of TKA geometry on the resulting joint mechanics and then as an iterative design-phase tool to develop implant geometry which improves dynamic mid-stance stability. To verify the predictions of the computational model, the new geometry was compared to an existing TKA in a cadaveric study utilizing the experimental simulator. This comparison enabled assessment of the accuracy of the computational model and illustrated whether the simulations were sensitive enough to appropriately differentiate subtle changes in implant design and the resulting kinematic patterns.

Methods

A previously validated specimen-specific finite element model of a cadaveric knee in the KKS[2], including specimen-specific bony geometry and soft-tissue representations, was implanted with multiple prototype implant geometries. Design iterations implicated an abrupt change from the sagittal femoral distal radius to the posterior radius as responsible for the anterior slide seen in vivo. Based on this understanding, a gradually reducing sagittal femoral radius was developed and incorporated into the updated femoral design (Fig. 1).


Kansas Knee Simulator

Kansas Knee Simulator

Figure 1: The Kansas knee simulator (left) and the computational representation of the simulator (right).

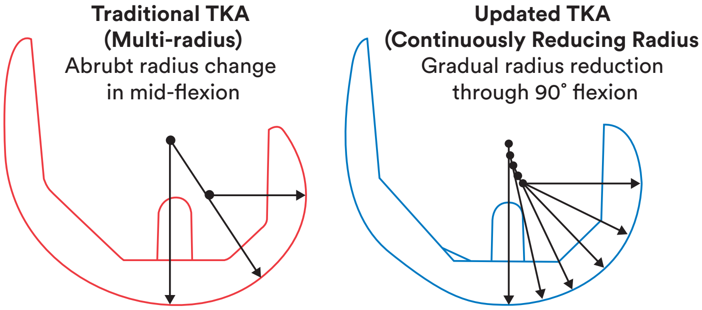


Figure 2: Comparison of femoral sagittal curvatures for the traditional multi-radius TKA (left) and the updated design with a gradually reducing radius (right).

Six cadaveric knees were implanted with a traditional multi-radius TKA design and mounted into the KKS[3]. A simulated deep knee bend (DKB) was performed on the knees between 10° and 100° flexion driven by a force applied to the quadriceps tendon to balance a body-weight force applied at the hip. The medial-lateral (M-L) translation and all rotations at the ankle were unconstrained. Subsequently, the traditional TKA was replaced with the updated TKA geometry, incorporating the gradually reducing sagittal femoral radius of curvature, and the cycle repeated. Knee motion was measured using an Optotrak 3020 (Northern Digital Inc., Waterloo, Ontario, Canada) and six-degree-of-freedom tibiofemoral kinematics described using a three-cylindrical open-chain model[4]. Additionally, the contact points between the insert and femoral component were approximated by identifying the lowest point on the femoral geometry along the superior-inferior (S-I) axis of the tibia.

Results

Both the computational and experimental simulators were able to identify key relationships between the implant shape and the contact mechanics, including the abrupt anterior slide of the femoral condyles of the traditional TKA at the transition from the distal to posterior sagittal radius of curvature (Fig. 3, left). In comparison, the gradually reducing femoral sagittal radius of curvature attenuated the anterior slide of the medial femoral condyle and led to a gradual posterior translation of the lateral condyle with knee flexion (Fig. 3, right). Although not statistically significant, the cadaveric knees on average experienced increased femoral rollback with the updated design.

Discussion

In vitro experimental and computational simulations are critical pre-clinical tools in the evaluation of new implant designs. The combined experimental and computational approach described here was able to relate subtle design changes in the sagittal femoral radius of curvature to A-P stability during a DKB and femoral rollback in flexion. While the models were able to identify and enable a solution to a clinically observed phenomenon, current and future work is focused on improving the fidelity and validation of the computational simulations to represent more sophisticated activities of daily living like gait, navigating stairs, and rising from a chair.

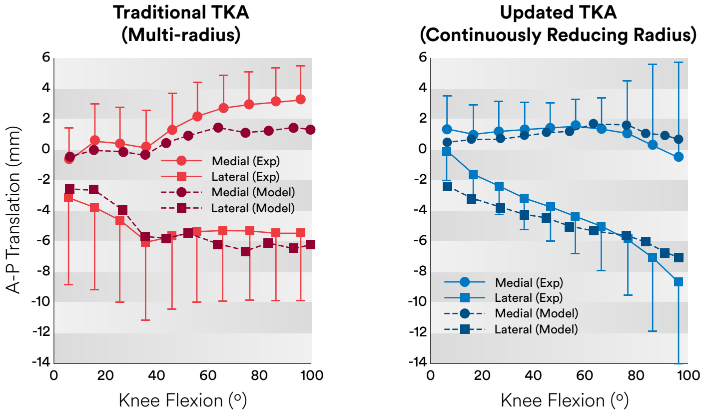


Figure 3: A-P condylar translations measured in the KKS and predicted by the computational simulator for the P.F.C.™ SIGMA™ System (left) and ATTUNE™ Knee (right) Implants.

Significance

This study utilized computational and experimental knee simulations to identify the relationship between TKA implant shape and a clinically observed kinematic phenomenon and then enabled design changes to address the paradoxical motion.

References

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