THE INFLUENCE OF CONTEMPORARY KNEE DESIGN ON HIGH FLEXION: *A KINEMATIC COMPARISON WITH THE NORMAL KNEE*

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INTRODUCTION

Although Total Knee Arthroplasty (TKA) surgery enjoys 90% of outcomes with good to excellent results, some patients have difficulty adjusting their gait to accommodate the new articulations inherent in contemporary implant designs. Paradoxical motions inclusive of anterior sliding and lateral pivot are examples of aberrant TKA kinematics.

This paper compares the motion of six contemporary TKA designs with recent in vivo kinematic data of the healthy un-operated knee through deep flexion[1] by employing a computational kinematic simulator.

Three designs employing tibial insert post and femoral cam motion control mechanisms were evaluated, Legacy LPS-Flex Fixed Bearing (Zimmer), Journey (Smith & Nephew), and Vanguard PS (Biomet), as well as three non post and cam designs, the MRK (Finsbury), Duracon and Triathlon (Stryker). All six designs are fixed plateau and currently available for clinical use in the United States.

COMPUTATIONAL KINEMATICS

LifeMOD/KneeSIM (LifeModeler, Inc., San Clemente, California, USA), a dynamic, validated musculoskeletal modeling system was utilized in this study. It provides a musculoskeletal modeling environment of the left leg of a nominal sized patient in which activities such as walking gait, lunge, stair ascent and descent and deep knee bend may be simulated. Activities are propelled by muscle forces and constrained by soft tissues.

Solid models of scanned TKA component geometries are arranged in the joint space to reflect a successful virtual surgery (Figure 1). A specified activity is simulated and animations and plots of component and soft tissue positions, forces and moments are generated.

Factors influencing kinematic function and stability of the knee joint, including surgical technique, component placement, design, and soft tissue disease state may be varied within the KneeSIM modeling environment. Patient anthropometrics may also be varied.

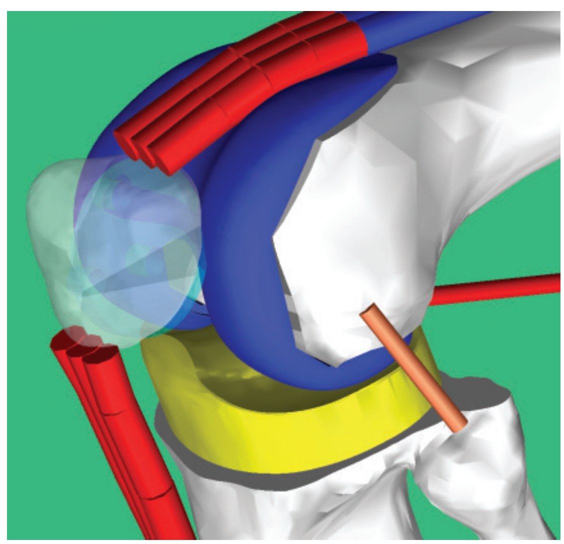


Figure 1: LifeMOD/KneeSIM, a dynamic, validated musculoskeletal modeling system.

LIFEMOD/KNEESIM VALIDATION

Anecdotal validations were performed comparing kinematic performance of a KneeSIM model of the Duracon knee implant to fluoroscopy (Figure 2) and retrieval wear scar data (Figure 3) available in the peer reviewed literature. The KneeSIM model captured distinct signatures of femoral component motion similar to that captured by the fluoroscopy data.[2]

Further, the tibio-femoral contact stress accumulated on the surface of the insert during walking gait and deep flexion activity cycles in the KneeSIM model predicted an unusual wear scar pattern that closely matched clinical retrieval data for 17 Duracon tibial inserts[3].

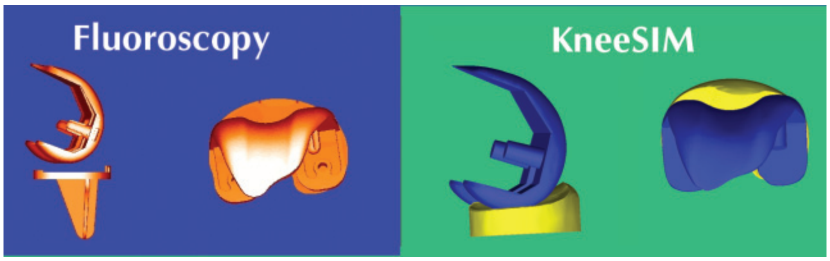


Figure 2: Fluoroscopy and KneeSIM compare favorably.

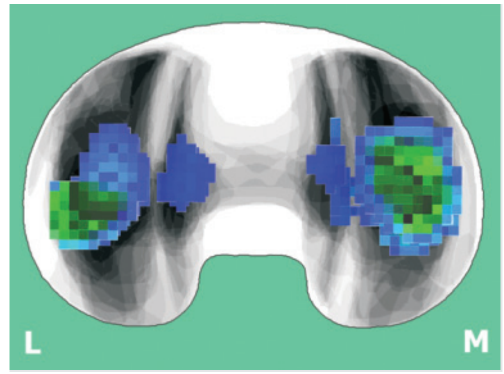


Figure 3: Retrieval wear scar data and KneeSIM overlay of accumulated pathways of contact stress.

STUDY METHODS

Three-dimensional solid models of the femoral, patellar and tibial insert components were created for each total knee design using laser profilometry to measure the articular surfaces of implantable quality parts.

Unique flexion facet centers[4] (FFC) were determined for each femoral component using computer aided design tools (Figure 4). A sagittal plane was cut through each femoral condyle and a circle approximating the posterior condyle articulating surface was created. The FFC is depicted as a sphere at the circles' center. Medial and lateral flexion facet centers were joined to create a "barbell" structure, which was rigidly affixed to the femoral component to better visualize its motion. The virtual components were "implanted" in the KneeSIM joint space per the manufacturer's surgical procedure. The posterior cruciate ligament was virtually resected in all six cases studied.

An initial analysis of a deep flexion activity to 160° of knee flexion was conducted to determine the maximum flexion angle achievable with each design. For the purposes of this study, impingement of the posterior femoral bone cut surface (Figure 5a) with the tibial insert (Figure 5b) was considered the first event that would impede knee flexion, and thus defined the maximum flexion angle.

Component motions were captured as animations <http://orl-inc.com/assets/comparison>. Anterior/posterior translation of the medial and lateral flexion facet centers were plotted in relation to FFC reference points for the healthy un-operated knee during deep knee bend activity[1].

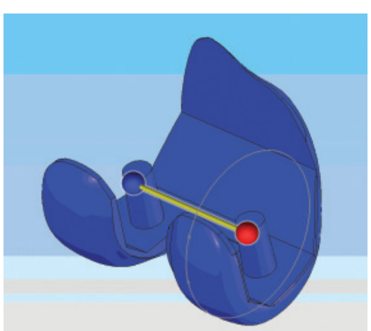


Figure 4: Determining flexion facet centers.

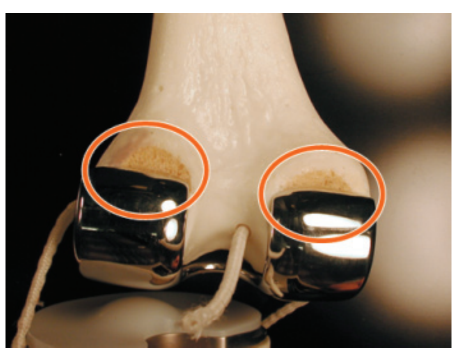


Figure 5a: Posterior femoral bone cut surface.

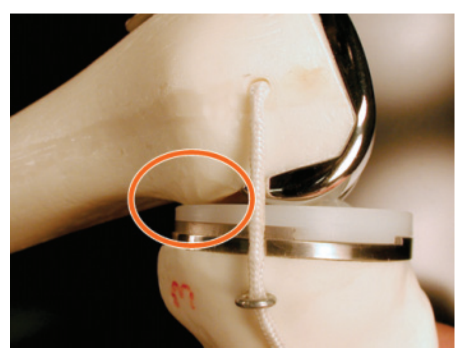
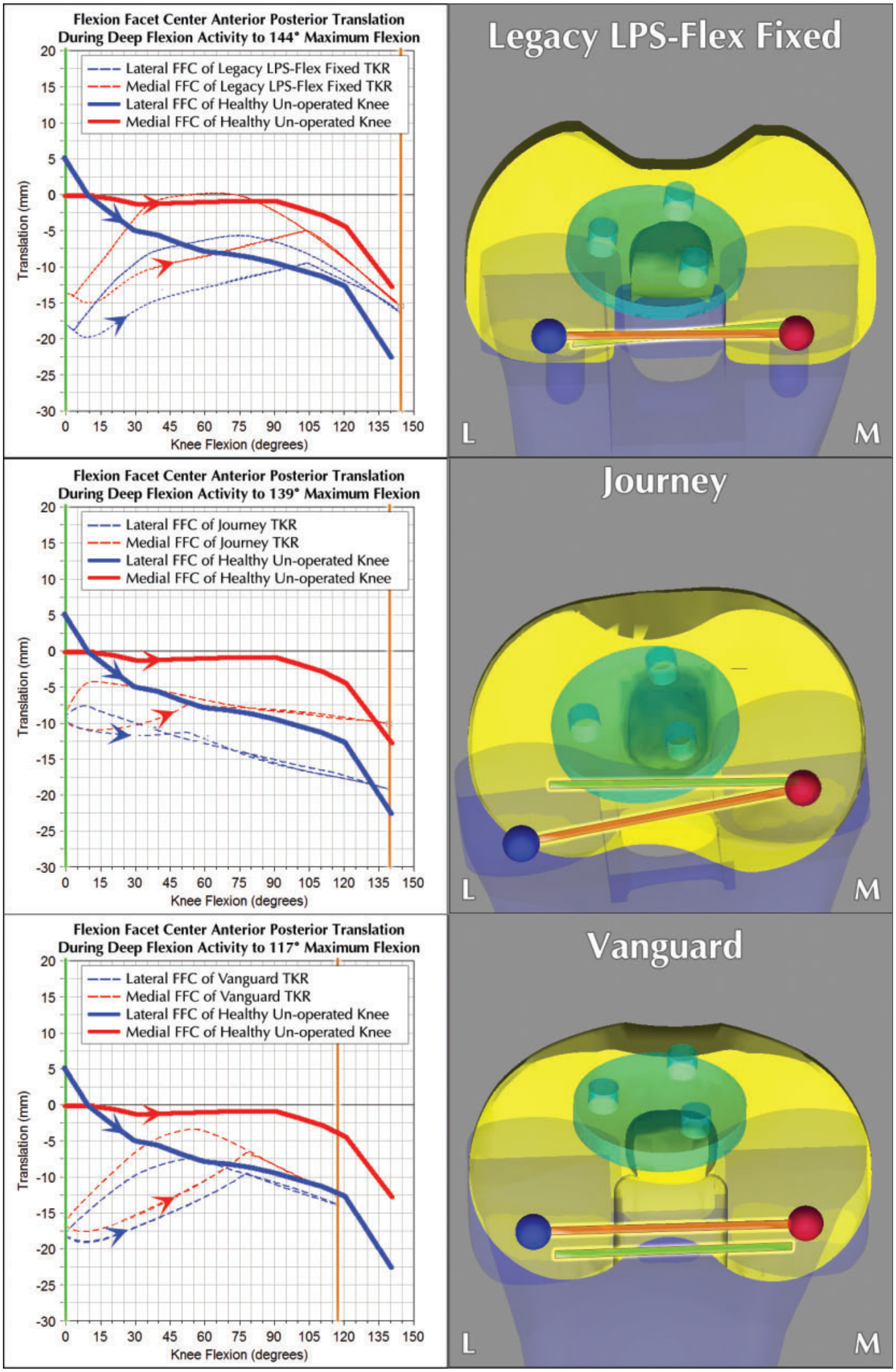


Figure 5b: Maximum flexion defined by bony impingement.

RESULTS

The resulting animations and plots characterize motion of the femoral component relative to the tibial insert in comparison to that of the normal knee. Each design flexes until the posterior femoral bone cut surface impinges against the tibial insert.

Figures 6a, 6b, 6c and Figures 7a, 7b, 7c represent the moment when maximum flexion occurred for each design. The plot on the left illustrates anterior (positive values) and posterior (negative values) translation of the flexion facet centers as a function of knee



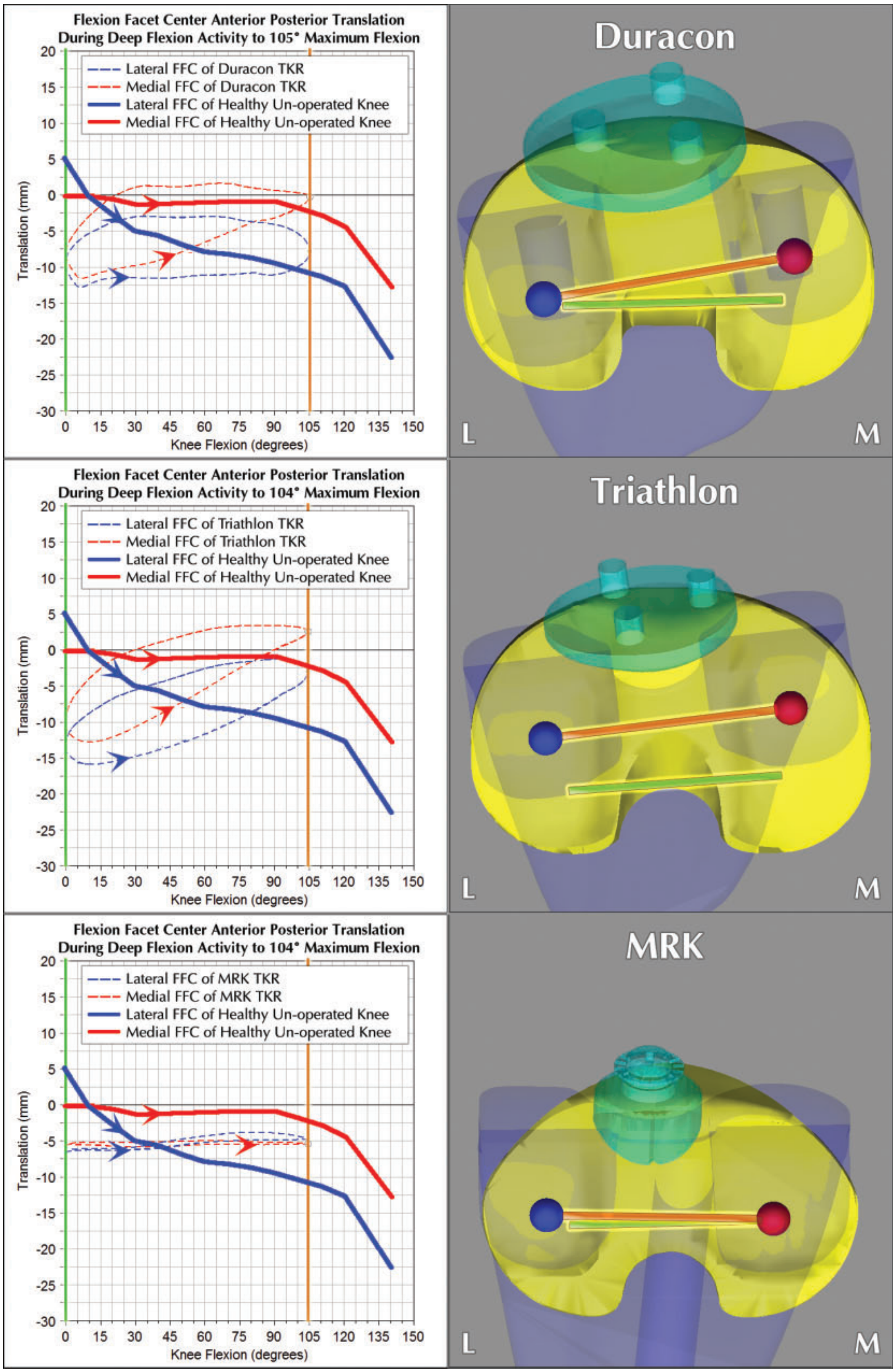
(a)

(b)

(c)

Figure 6

flexion angle. The image on the right depicts component orientation at maximum flexion appreciated from a superior view. The blue sphere represents the location of the lateral FFC, and the red sphere the location of the medial FFC. Initial location of the FFC barbell at zero degrees of knee flexion is marked as a green bar, the location of the FFC barbell at maximum flexion is marked as an orange bar. These reference points contribute to understanding the relative motion of the femoral component. Designs are presented in descending order of maximum knee flexion.



(a)

(b)

(c)

Figure 7

DISCUSSION

The Legacy LPS-Flex Fixed (Figure 6a) achieved the highest flexion angle among the designs studied. Design features contributing to this outcome include a post/cam mechanism that promotes femoral component contact near the posterior edge of the tibial insert, a small femoral posterior condylar radius and above average thickness of the posterior femoral condyles, (Figure 8) a recognized disadvantage of which is a requirement for added posterior femoral bone resection.[5] At full extension, impingement of the anterior aspect of the femoral cam and tibial post was observed. During deep flexion, the femoral component rolls and slides anteriorly until the femoral cam and tibial post articulate at 105º of knee flexion.

Of the designs studied, the Journey (Figure 6b) most closely replicates healthy un-operated knee kinematics. In general, the femoral component consistently rolls back after engaging the cam and post at 54º of flexion and offers a medial pivot, both hallmarks of normal knee motion.

The Vanguard PS (Figure 6c) design rolls and slides anteriorly until engaging the post cam mechanism at 78º of flexion. Femoral rollback is achieved 4 mm anterior to the starting position when maximum flexion occurs, diminishing the design's capacity to achieve deep flexion without bony impingement.

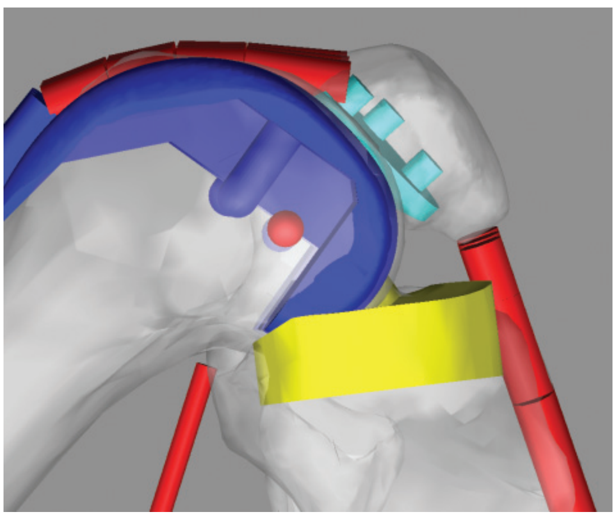


Figure 8: Medial view of Legacy LPS-Flex Fixed at its maximum flexion of 144º.

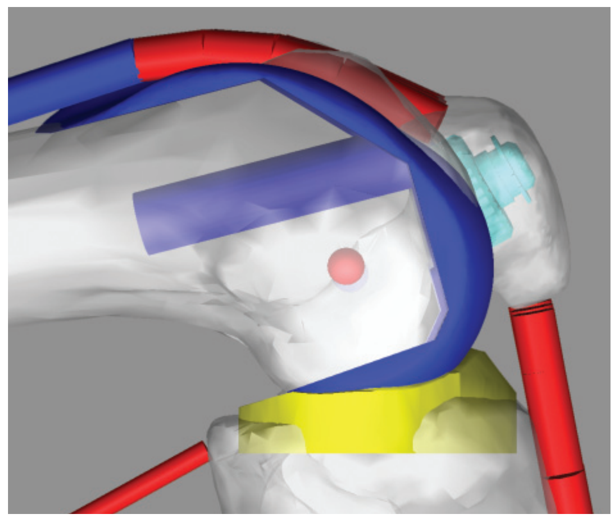


Figure 9: Medial view of MRK at its maximum flexion of 104º.

The Duracon (Figure 7a) and the Triathlon (Figure 7b) provide less anterior posterior constraint and both exhibit paradoxical lateral pivot motion during high flexion. In addition, the Triathlon exhibits paradoxical motion of anterior sliding, rather than the femoral rollback exhibited by the healthy un-operated knee. The effect of retaining the posterior cruciate ligament on constraining anterior sliding in these designs is the subject of future work.

In contrast, the MRK (Figure 7c) employs a highly conforming ball in cup geometry between femoral component and tibial insert in the medial compartment. This design encourages pivot while highly constraining anterior and posterior motion. The lateral compartment is less conforming and allows a small amount of anterior motion.

In general, all of the non post and cam designs studied developed tibio-femoral contact in the central or anterior portion of the tibial insert, thus decreasing their capacity to achieve deeper flexion (Figure 9).

Flexion facet centers do not indicate locations of contact area, but rather serve as reference points to help visualize motion of the femoral component relative to the tibia. Close inspection of the dynamic animations in the study results reveals that contact areas (light yellow patches) are often coincident with the FFC marker from a superior view, but can readily diverge during activity.

CONCLUSIONS

The knee implant designs investigated did not replicate the kinematics of the healthy un-operated knee. Post and cam designs achieved higher flexion than non post and cam designs. The post and cam mechanism drove tibio-femoral contact toward the posterior edge of the insert, allowing higher flexion prior to impingement. Non post and cam designs demonstrated contact in the central or anterior areas of the insert during high flexion, diminishing their ability to achieve high flexion prior to posterior bony impingement.

THE REMAINS OF THE DAY…

A knee arthroplasty that closely approximates the feel and function of a healthy, un-operated knee is increasingly identified by both patients and clinicians as an objective of knee replacement surgery.[6,7]

Dynamic, validated computational kinematic simulation expands the methodologies available to investigate and better understand factors influencing knee kinematics following TKA. LifeMOD/KneeSIM is a powerful, evolving technology that holds great promise for knee design optimization leading to improved patient outcomes.

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