THE INFLUENCE OF MECHANICAL VERSUS KINEMATIC ALIGNMENT ON KNEE DESIGN PERFORMANCE DURING WALKING GAIT

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INTRODUCTION

The goals of total knee arthroplasty (TKA) are to eliminate pain and restore knee function to enable a return to daily activities. The classic mechanical alignment (MA) surgical procedure aspires to consistently establish neutral limb alignment, regardless of the degree of patient pre-operative varus or valgus alignment, and create a joint line perpendicular to the mechanical axis. However, the more recently performed kinematic alignment (KA) surgical procedure seeks to restore patient limb alignment and joint line to the individual patient's pre-diseased state, referencing the flexion-extension axis. This computational kinematics study investigates the effect that these two surgical methods have on metrics associated with predicting long term outcomes for a Triathlon CR design (Stryker Orthopedics) which is cleared for clinical use in the United States.

MECHANICAL ALIGNMENT

Figure 1 illustrates the mechanical axis, an imaginary line connecting the hip joint center to the ankle center in an anterior-posterior (AP) view. This axis is typically 3 degrees from the vertical axis when a patient is standing comfortably. The goal of MA bone resections is to be perpendicular to the mechanical axis, theoretically promoting even distribution of contact forces across the medial and lateral compartments of the tibial-femoral component articulation, reducing implant loosening.

The mechanical axis is difficult to directly determine in the surgical theater, however, there are many methods of indirectly determining its location. External guidance such as computer aided surgery, patient specific instrumentation and extramedullary and intramedullary femoral and tibial bone guides are used with anatomical references such as the posterior condylar axis, anteroposterior axis and transepicondylar axis to position bone resection saw guides. The transepicondylar axis is depicted in **Figure 1**, and the bone resection planes are perpendicular to the mechanical axis with 3 degrees of tibial posterior slope, as recommended by the Triathlon CR surgical procedure. This defined the orientation of the components for the MA experiment conducted with a computational knee simulation of walking gait.

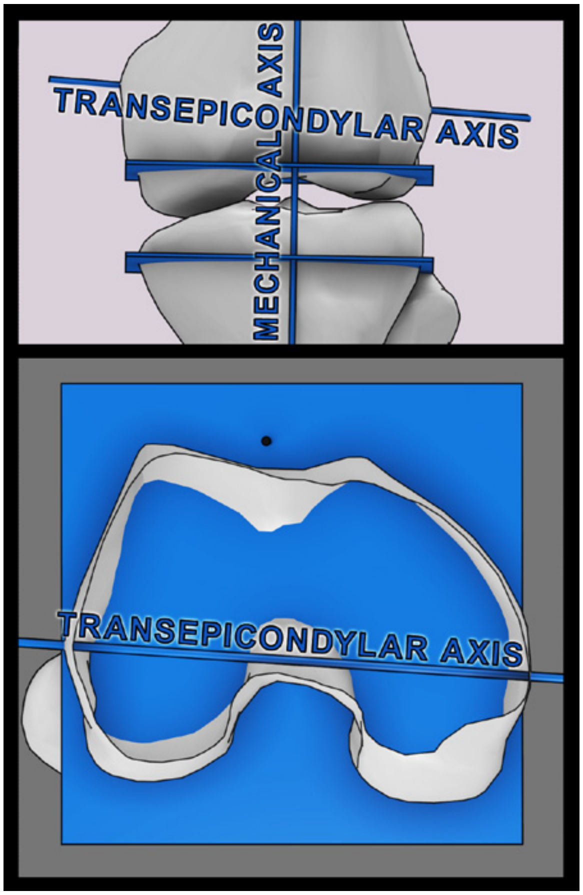

Figure 1 - *Reference axes and bone resection planes for mechanical alignment (MA).*

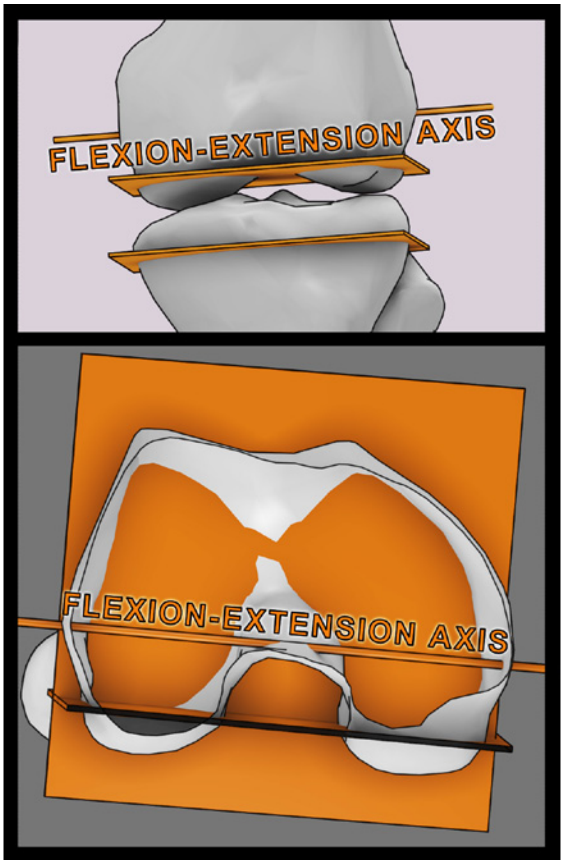

Figure 2 - *Reference axis and bone resection planes for kinematic alignment (KA).*

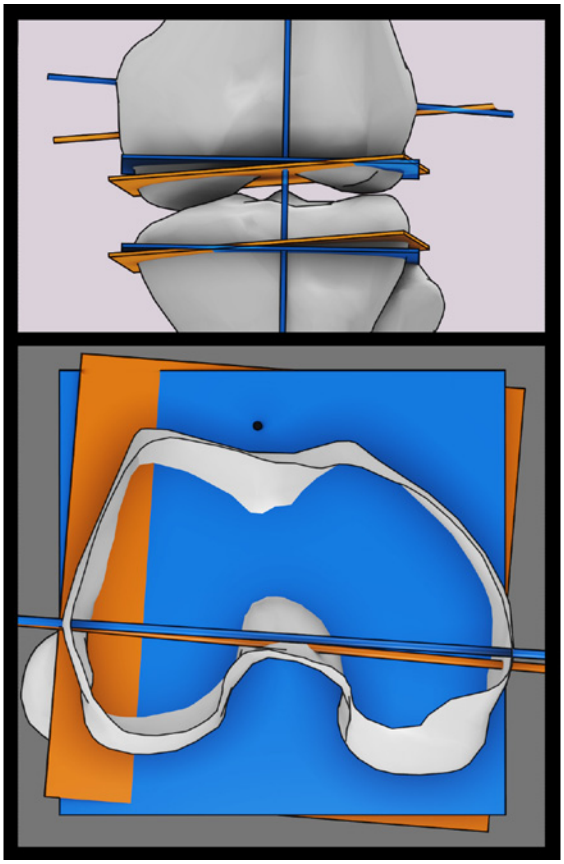

Figure 3 - *Comparison of reference axes and bone resection planes for both MA and KA.*

KINEMATIC ALIGNMENT

The KA surgical procedure[1] resects distal femoral and proximal tibial bones so that component articulating surfaces best fit the individual patient's estimated healthy cartilaginous surface anatomy. **Figure 2** illustrates the flexion-extension axis (FEA), an imaginary line passing through the geometric centers of each posterior femoral condyle, which closely parallels a patient's joint line in the AP view. Equal resection of the posterior condyles, allowing for cartilage wear and saw kerf, ensure that this resection surface is parallel to the FEA from an axial view. Similarly, equal thickness distal femoral bone resection ensures that the surface is parallel to the FEA from an AP view.

When the thickness of the implanted femoral component condyles match the thickness of the equally resected bone, the articulating surface of the femoral component will restore the patients original cartilaginous surface and be accurately aligned with the flexion-extension axis. The value of this alignment is that undue strains of collateral ligaments do not occur in mid and deep flexion and soft tissue releases are not needed for a successful outcome.

The proximal tibial bone is resected to restore the individual patient's original varus and posterior slope. The axial rotation of the tibial component aims to closely match the axial rotation of the femoral component. The patellar component is typically implanted in a natural position without any lateralization of the component. The patient's pre-operative limb alignment is often restored because their original joint line is restored.

Because KA is patient specific, relying on methods that restore an individual patient's distal femoral and proximal tibial anatomy, the positions of TKA components implanted using this procedure vary as much as natural contralateral anatomy does[2]. For the purposes of positioning KA components for this study, average values of reported post-operative KA component positions were gathered from the literature[3,4].

Figure 3 illustrates the differences between bone resections used in this study for the MA and KA experiments. The KA femoral component used in this study was 6 degrees more flexed, 3 degrees more valgus and 4 degrees more internally rotated than the MA femoral component. The tibial insert followed the femoral component, 3 degrees more varus and 4 degrees more internally rotated. The proximal tibial posterior slope for the KA procedure was not changed from the 3 degrees used in the MA procedure, as no reports in the literature describing that KA distribution were found.

COMPUTATIONAL KINEMATICS

KneeSIM, a dynamic, validated musculoskeletal modeling system[5] was utilized in this study, providing a computational modeling environment of the left leg of a nominal sized patient. Solid models of the Triathlon CR component geometries were arranged in the joint space to reflect a successful virtual surgery employing MA (**Figure 4**), then repeated for KA. All model parameters were held the same except for TKA component positions. The definition of walking gait established by the International Organization for Standardization (ISO)[6] was applied. The activity cycle was propelled by quadriceps and hamstring muscle forces and constrained by TKA component articulation and soft tissues, including an intact posterior cruciate ligament. The resulting component motions, articulations, and contact forces were recorded for the second cycle of activity (after steady state had been achieved) for both MA and KA models and the results compared.

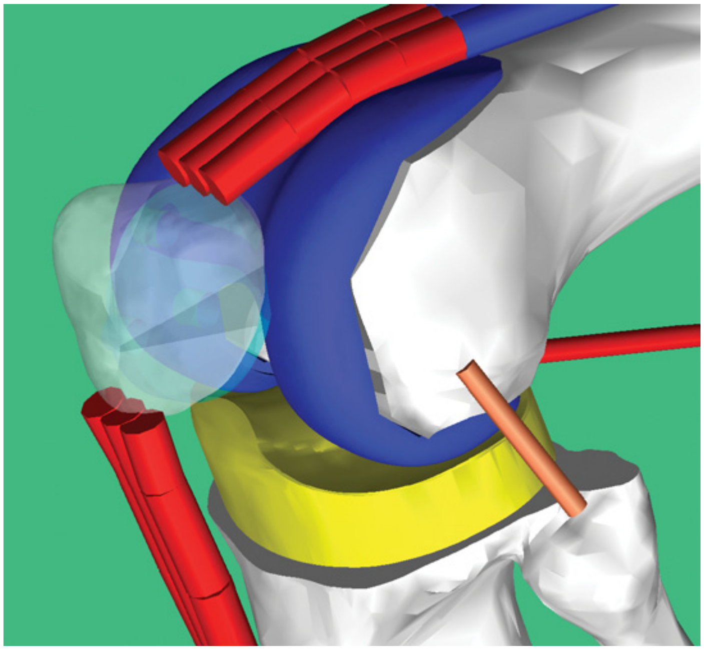

Figure 4 - *KneeSIM, a dynamic, validated, computational musculoskeletal modeling system.*

RESULTS

There were subtle differences between the MA and KA metrics of femoral and patellar component motions, contact articulations and forces, but average absolute differences over the stance phase of walking gait were less than 2 mm, 2 degrees and 200 Newtons for all results recorded. Tibial-femoral articulations had different loading profiles across the medial and lateral compartments during stance (**Figure 5**), however, no clear trend was discernible between MA and KA surgical procedures. Lateral compartment liftoff nearly occurred before toe off for the MA results and did occur at toe off for the KA results. Patella contact and lateral shear forces were very similar for both cases. A video presentation of all results is available at http://orl-inc.com.

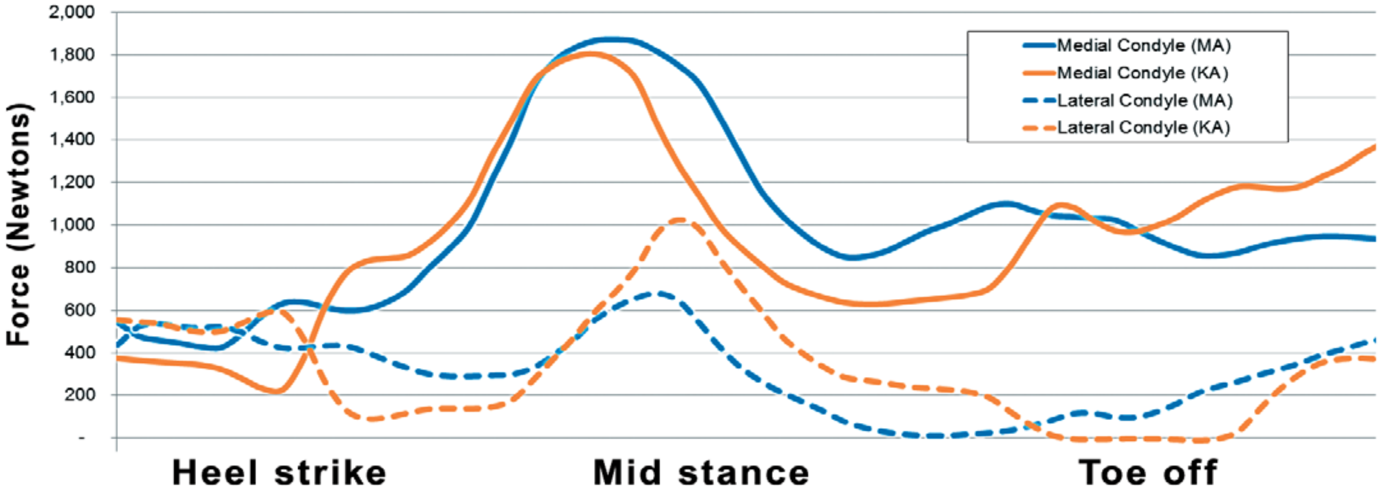

Figure 5 - *Tibial-femoral component contact force magnitudes during the loaded stance phase of walking gait for the medial and lateral compartments of both MA and KA experiments.*

DISCUSSION

Computational models provide some clarity in complex environments, as many parameters may be held constant while only a select few are changed to test their effect. Patient variables and TKA component design were held constant in this study, allowing the effect of varying the surgical alignment procedure from mechanical to kinematic alignment to be understood. The study results of component motions and patella tracking are associated with patient satisfaction, and contact forces and articular wear paths are associated with implant longevity. All were functionally the same for both surgical procedures.

Although the medial and lateral contact forces varied between MA and KA during the loaded stance phase of walking gait, there was no discernible trend to determine if one was different than the other. Peak differences could be as high as 400 Newtons for a brief moment, in favor of MA or KA equally, but averaged absolute differences were less than 200 Newtons. Simply averaging the forces over the entire gait cycle yielded differences of 65 Newtons, suggesting long term accumulated wear results would not differ.

This study relied on statistical TKA component positioning literature data instead of using multiple three dimensional patient bone geometry data sets and following the KA surgical procedure[7]. This has the strength of representing average KA positioning over many patients but did not capture the variability that is inherent in patient anatomy which KA aspires to closely replicate. Shortcomings of the ISO walking gait standard[8] could be improved with more current and accurate information, and is the focus of future work.

Different TKA component geometries that are asymmetrical or single radius or more conforming than the Triathlon CR may demonstrate wider differences than the results presented here, and require individual evaluation. More demanding activities such as stair climb or deep knee bend may also have that effect.

CONCLUSION

No functional difference was found between mechanical and kinematic alignment surgical procedures during the ISO walking gait cycle with Triathlon CR TKA components. Other product designs that are asymmetrical or offer greater articular conformity than the Triathlon CR design may yield different results.

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