Do different alignments require different implant designs? a biomechanical study

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INTRODUCTION:

The original design of each total knee arthroplasty (TKA) implant is primarily determined by industrial manufacturers based on a specific alignment "philosophy." However, the in-vivo performance of these implants heavily relies on the surgeon's decisions regarding position, orientation, and management of the surrounding soft tissue envelope. While this aspect is of utmost importance, it remains a subject of intense debate, and a clear, standardized approach has not yet been established.

Among the various alignment strategies, mechanical alignment (MA) and kinematic alignment (KA) are the most prevalent. In MA, the tibial and femoral components are positioned perpendicularly to the mechanical axis of the respective bones. Conversely, KA involves realigning the TKA components to match the native joint line, with the goal of restoring the knee's natural kinematics.

Numerous studies have attempted to compare the clinical outcomes associated with these different alignment approaches. However, definitive results have not been achieved, and there is still a lack of long-term unbiased multicentric follow-up studies. Additionally, it is important to note that surgeons sometimes choose a surgical alignment approach based on their personal preferences, which may not match with the rationale behind the TKA implant. This means that components designed for traditional mechanical alignment may be implanted using a kinematic alignment technique, leading to potential discrepancies that can impact clinical outcomes and complicate their interpretation.

The objective of this research, therefore, is to biomechanically compare the two alignment philosophies in different TKA designs using a validated finite element model.

METHODS:

This study is performed using finite element analysis, developing a knee finite element model of a TKA based upon an already validated and published model.

To model the bone, the geometry of a Sawbones tibia (right side, size medium) was selected in agreement with previous studies. The orthopedic devices used in the model are based on data provided by an industrial prosthesis manufacturer.

Four distinct configurations are analyzed in this study:

- MA with a symmetric polyethylene thickness implant, resulting in a joint line orthogonal to the bone cuts;
- MA with an insert featuring an asymmetric thickness (Asymmetric-MA), aiming to achieve a joint line closer to the physiological alignment, resembling the target for kinematic alignment (KA);
- KA with a tibial stem orthogonal to the tibial cut, thus not aligned with the tibial axis.
- KA with the tibial stem aligned with the tibial axis (Ortho-KA).

Each model was loaded with a 2500N vertical force, to simulate the peak of loads during walking. The study's output involves extracting and comparing polyethylene and tibial bone stress in several regions of interest.

RESULTS:

Each configuration of TKA design and alignment, under the same loading conditions, leads to different insert and bone stress distributions. Therefore, it is essential to analyze each interface when comparing the different configurations.

In detail, in the case of a symmetric insert, the stress distribution on the polyethylene is more uniformly distributed between the medial and lateral compartments, as opposed to the distribution observed with an asymmetric insert (refer to Figure 1). A similar homogeneous stress distribution is observed in the bone, as measured by the von Mises stress, when a symmetric insert is utilized (see Figure 2).

With the use of KA, the presence of a conventional tibial stem results in increased stress levels in both the polyethylene insert and the bone compared to when an orthogonal tibial stem is used.

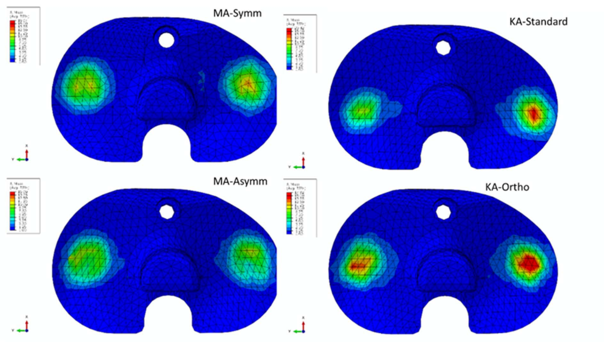
In terms of contact biomechanics, MA demonstrated physiological load transfer, while asymmetric-MA exhibited a redistribution of contact due to thickness variations. KA showcased an increased contact area, with ortho-KA demonstrating intermediate results between MA and KA. Comparable findings were observed when analyzing bone von Mises stress. However, ortho-KA exhibited higher shear stress.

Figure 1 – Von Mises stress in the polyethylene insert for the different configurations.

Figure 2 –Von Mises stress in the tibial bone for the different configurations.

DISCUSSION AND CONCLUSION:

Modifications in alignment and bone-implant interaction induce alterations in the tibiofemoral and bone-implant interface. As a result, different alignment approaches necessitate specific implant designs. However, these changes, though of minor magnitude, contribute to the challenges in identifying the optimal strategy. Surgeons should take into account these nuances when selecting implants and determining the alignment approach, recognizing the potential impact on clinical outcomes.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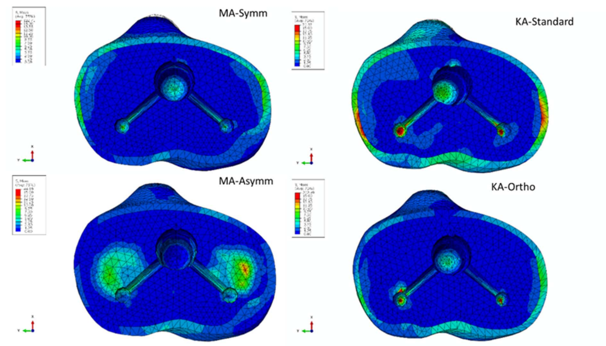
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