Effects of Total Knee Replacement Material Pairing on Implant Kinematics and Stability

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INTRODUCTION: The intrinsic constraint of a TKR system is an important metric for determining the stability of the implant, and candidate designs are traditionally assessed using either computational or experimental techniques. While computational techniques enable more rapid assessment which can streamline the design process, it is also important to perform physical testing to validate computational results and further screen candidate designs. However, manufacturing physical prototypes can be expensive and time consuming, particularly for metal components. The time and cost associated with manufacturing physical prototypes could be reduced if 3D printed plastic components were shown to yield similar results as metal-on-plastic articulations; however, "stiction" (loosely defined as an elevated static coefficient of friction) can be a factor to plastic-on-plastic articulations, and may significantly affect implant behavior. Thus, the abstract objective is to compare the kinematics and intrinsic constraint of metal-on-plastic (M-P) and plastic-on-plastic (P-P) implants under physiologically relevant loading, with and without simulated ligament contributions, in order to elucidate the effects of material pairings.

METHODS: A cruciate retaining TKR implant was created by combing a 3D printed ABS plastic tibial component, based on the geometry of a commercially available TKR system (DePuy Synthes SIGMA® Posterior Cruciate Retaining TKR, Warsaw, IN) with the standard cobalt chrome femoral component, as well as a 3D printed ABS plastic replica femoral component. This results in both M-P and P-P articulations. Implant components were mounted to the femoral and tibial actuators of a VIVO 6-DOF joint motion simulator (AMTI, Watertown, MA), which was used for *in vitro* constraint testing using *functional* laxity tests which we have described previously[1]. These tests were performed by measuring TKR joint kinematics during simulated gait, using loading previously reported in the literature[2], in order to define the normal path of motion of the knee (where knee refers to the implant components, as well as any virtual soft tissue contributions which are simulated during the experiment). Tests were then repeated with superimposed anterior-posterior (AP) and internal-external torque (IE) loads, which were proportional to the time-varying compressive force passing through the joint. Constraint was measured based on resulting deviations from the normal path in the AP and IE directions, respectively. The posterior cruciate and collateral ligaments were simulated as tension-only point-to-point springs using the soft tissue modelling capabilities of the VIVO, and their material properties were based on subject-specific parameters previously published by the MB Knee project[3]. In order to observe any possible interactions between material pairings and ligament properties, the experiments were performed with all ligaments disabled, and then repeated using two different sets of simulated ligaments.

RESULTS: Figure 1 shows the AP and IE kinematics when the M-P and P-P material pairings were used during one simulated gait cycle without virtual ligaments. AP and IE kinematics both varied when the femoral component was changed from metal to plastic; however, the IE kinematics had a similar trend between the two material pairings. Figure 2 summarizes all of the kinematic data across one gait cycle with and without virtual ligaments. The P-P implant had anteriorly-offset AP displacements and internally-offset IE rotations compared to those of the M-P implant. However, as shown in Figure 3, the functional laxities of the two implant material pairings are nearly identical. Ligaments had little to no effect on AP or IE kinematic, and generally reduced both AP and IE functional laxity.

DISCUSSION: Different kinematics were observed between the M-P and P-P implants. AP and IE offsets as well as different AP and IE ranges of motion may be the result of different initial implant positioning on the joint motion simulator. This could also be due to "stiction" occurring for the P-P implant. These factors will be further investigated in future work. Although kinematic differences were apparent, the functional laxity of the implant system tested appears to be relatively insensitive to the material pairing. Surprisingly, implant kinematics and functional laxity showed very little sensitivity to the presence and properties of simulated soft tissues. We suspect that this trend may be related to implant shape, and that while this particular implant system showed little sensitivity to ligaments, other implant systems may. These relationships are complex and hard to predict, which underscores the importance of pre-clinical *in vitro* testing.

SIGNIFICANCE: Physical testing of TKR systems to assess stability is an important aspect in screening candidate TKR designs which can be expensive and time consuming. This investigation aims to reduce those costs by utilizing inexpensive 3D printed plastic components, which are shown to produce similar constraint behaviors as metal-on-plastic articulations.

REFERENCES:

[1] Anderson et al., "Development of Clinically Relevant Constraint Measurement Using Modified Total Knee Replacement Implants." *SB^{3}C*, 2016
[2] Bergmann et al., PlosOne, 2014 [3] https://simtk.org/projects/mb_knee/

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IMAGES AND TABLES:

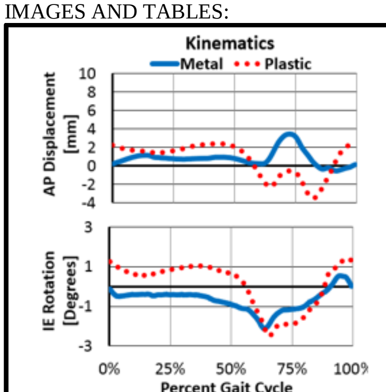

Figure 1: AP (top) and IE (bottom) kinematics for M-P and P-P implants, without virtual ligaments.

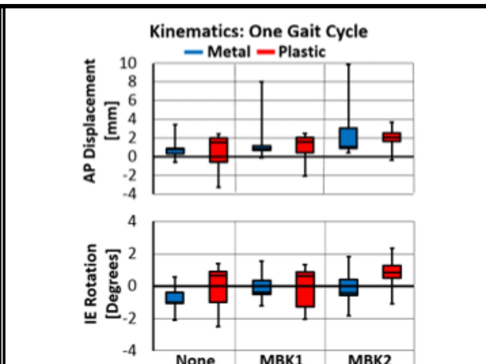

Figure 2: AP (top) and IE (bottom) kinematics for M-P and P-P implants without (None) and with virtual ligaments (MBK1 and MBK2).

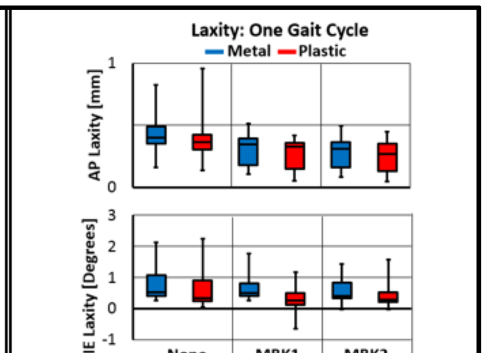

Figure 3: AP (top) and IE (bottom) laxity for M-P and P-P implants without (None) and with virtual ligaments (MBK1 and MBK2).