The Impact of Increasing Polyethylene Thickness on Knee Stiffness in a Surrogate Total Knee Arthroplasty Model

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INTRODUCTION: Avoiding stiffness and achieving optimal outcomes in total knee arthroplasty (TKA) relies on restoring physiologic balance in the soft-tissue envelope around the knee. After balancing the knee, trial inserts of varying thicknesses are used to assess overall soft-tissue balance and stiffness. Intra-operative assessments are subjective in nature. A modified pendulum knee drop (PKD) technique offers a quantifiable approach to reliably estimate the soft-tissue stiffness of the knee joint by measuring the amplitude and decay rate of the oscillations when the leg is passively swung. Objectives of this study were to evaluate stiffness and motion in a total knee arthroplasty model by utilizing a PKD test with an inertial measurement unit (IMU) and various tibial implants with 1-millimeter (mm) increments to more accurately characterize soft-tissue tension.

METHODS: To assess knee stiffness changes with different implant insert thicknesses, the PKD test was performed on a mechanical bone total knee arthroplasty model with simulated soft-tissue structures that underwent a robotic total knee arthroplasty (RATKA). An IMU sensor system was used where one sensor was placed on the femur and one on the tibia, approximately 0.75 meters apart, to record the knee range of motion (ROM). There were three trials performed for each of the insert thicknesses, where the inserts varied in 1 mm increments ranging from 9 to 14 mm. The femur of the mechanical bone model was fixed to a table and the knee was then dropped from full extension and allowed to oscillate until rest. The IMU sensor system was used to measure knee ROM and the log decrement ratio and number of oscillations were estimated for each condition. A total of eighteen trials were conducted with three trials performed for each insert. The data was normally distributed and analyses of variance tests were used to assess significance between insert groups with a significance level set at 0.05 (95% confidence level) to determine whether there were statistically significant differences between inserts.

RESULTS SECTION: An increasing trend of stiffness was observed for all inserts with significant differences between 1 mm increments from 11 to 14 mm inserts (Figure 1). No significant differences were detected between the 9 and 10 mm inserts or the 10 and 11 mm inserts. Knee ROM was affected by changes in insert thickness, where a reciprocal pattern demonstrated that increased insert thickness resulted in decreased oscillations (R^2= 0.99). The 14 mm insert resulted in the greatest stiffness when compared to all other trial inserts with the least number of oscillations, $p<0.05$. An increase in insert trial thickness led to significantly stiffer knees as observed with the log decrement coefficient and peak oscillations, as seen in Figure 1.

DISCUSSION: A significant increase in knee stiffness was observed with increasing implant trial thicknesses using the PKD test. This suggests that an increase of as little as 1mm in implant thickness may lead to increases in stiffness of the knee. There is an exponential increase in stiffness until the ligament transition point is achieved, where the ligament tension increases from the toe region to the linear region, as seen by the considerable increase in stiffness after 12 mm, accompanied by a decrease in passive knee motion. These results may have important clinical implications as the PKD test could aid in the selection of the optimal insert thickness which may supplement soft-tissue balance. Overall, the study provides valuable insights into the relationship between implant trial thickness and knee stiffness and highlights the importance of the sensitivity of millimeter joint line changes.

SIGNIFICANCE/CLINICAL RELEVANCE: Currently, subjective manual techniques are used for intraoperative knee stiffness evaluations. Efforts to quantify soft-tissue stiffness through compartment pressures and ligament tension face challenges in defining optimal targets, given variations in tension impact and loading conditions. The PKD test offers promise as an objective measure for assessing knee stiffness in TKA and guiding decisions on tibial insert thickness.

IMAGES AND TABLES:

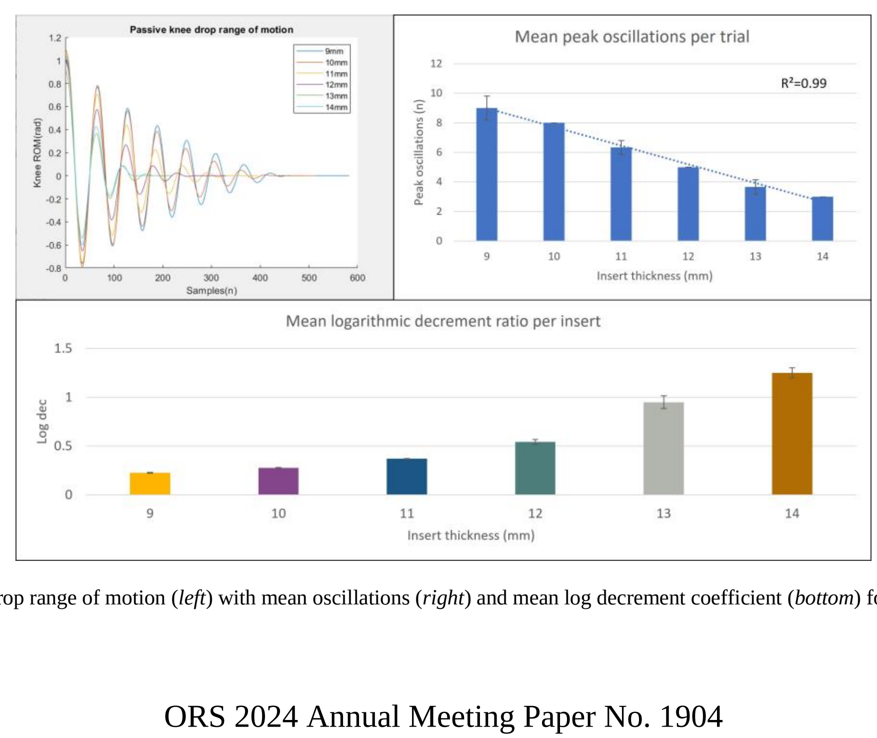

Figure 1. Passive knee drop range of motion (*left*) with mean oscillations (*right*) and mean log decrement coefficient (*bottom*) for all tibial insert thickness