Assessing the impact of total knee arthroplasty implants on knee stiffness with a passive knee drop test

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INTRODUCTION: Achieving optimal outcomes in total knee arthroplasty (TKA) greatly depends on maintaining an appropriate balance of soft tissues surrounding the knee joint. However, traditional subjective manual methods for assessing soft-tissue balance can be challenging to quantify and replicate consistently. To address this issue, a modified pendulum knee drop (PKD) technique has been proposed as a potential objective and reliable method for estimating knee joint soft-tissue stiffness. By measuring the amplitude and decay rate of oscillations when the leg is passively swung from extension to flexion, the PKD technique offers a novel approach to evaluate knee stiffness in a reproducible manner. This study aimed to explore the feasibility of using the PKD technique to assess knee stiffness by investigating a simulated TKA with different ligament tensions. Such findings could have important implications for improving the accuracy and objectivity of soft-tissue balance assessments in TKA procedures.

METHODS: Three fresh frozen cadaveric specimens thawed at room temperature for 24 hours before dissection underwent a robotic-assisted total knee arthroplasty (RATKA) procedure with surgical parameters identified in Table 1. To assess knee stiffness changes as a function of insert thicknesses, the PKD test was performed on each RATKA specimen where a planned insert was targeted to achieve a balanced knee and then increased by 2 millimeters (mm) to simulate a stiffer knee joint. An inertial measurement unit (IMU) sensor was placed on the tibia to record range of motion (ROM). The thigh of the specimen was abducted over the side of the surgical table to allow the shank to oscillate freely. The knee was placed into 45 degrees of flexion, as the calibrated reference position and released allowing the joint to oscillate until rest. The procedure was repeated three times for each of the implant thicknesses. The IMU sensor was used to measure knee ROM and the log decrement ratio was calculated for each condition to estimate knee stiffness and averaged over the three trials. The data was normally distributed and a paired samples *t*-test was used to assess significance within specimens. Stiffness ratios were calculated as the log decrement values of the thicker tibial insert divided by the log decrement value of the thinner tibial insert and were used to estimate the magnitude of stiffness increases.

RESULTS: The PKD was able to detect increased knee stiffness for all specimens as a function of increasing insert thickness, with two specimens having a two-fold increase in stiffness. This increase in stiffness was not impacted by implant type or implant size (Table 1). Specimen 2 had the lowest increase in stiffness following the 2 mm increase in insert thickness (Figure 1). A 2 mm increase in insert thickness equated to an increase in knee stiffness of 1.44 to 2.06 (Table 1), where the simulated knee stiffness condition demonstrated measurable results for each condition. The PKD demonstrated reproducible results with respect to log decrement estimations with an average standard deviation of 0.02 for all trials.

DISCUSSION: This study investigated the ability of a novel PKD test to quantify the relative change in the stiffness of a TKA when changing the thickness of tibial inserts. Comparing the stiffness ratios between test constructs demonstrated that the PKD test was sensitive to variations in stiffness associated with the increase in ligament tension caused by thicker inserts. A significant increase in knee stiffness was observed where a 2 mm incremental insert resulted in nearly twice the stiffness, as observed with the increase in log decrement values. The impact of implant size or design type suggests that these variables when appropriately sized and performed, do not impact stiffness as much as increasing ligament tension caused by incorrect insert selection, however, more samples are needed to confirm these trends. The ability of the PKD test to produce a sensitive and reproducible measure of relative construct stiffness is a promising new tool to help understand the impact of design and surgical technique on *in vitro* total knee arthroplasty models.

SIGNIFICANCE/RELEVANCE: Achieving ligament balance is one of the primary aims of a surgeon during TKA, yet most intra-operative assessments of ligament tension are subjective. Although compartmental pressures and ligament tension have been examined, they serve as surrogate endpoints rather than direct measures of actual construct stiffness. This study demonstrated that the PKD technique can objectively distinguish between different ligament tensions as represented by variations in tibial insert thickness. Further work correlating the log decrement coefficient of the PKD to patient outcomes could provide the surgeon with a reliable intra-operative test for assessing clinically-relevant TKA balance during surgery.

IMAGES AND TABLES:

Specimen ID	Tibial Implant	Tibia Size	Insert Sizes (mm)	Log Dec	Std	Stiffness ratio	*P*-value
1	CR	1	11	0.098	0.018	2.06	0.008
			13	0.201	0.013		
2	PS	4	9	0.241	0.013	1.44	0.069
			11	0.348	0.040		
3	PS	5	9	0.278	0.009	2.05	0.006
			11	0.570	0.030		

Table 1. Robotic-assisted total knee arthroplasty specimen information

Key: CR=cruciate-retaining; PS=Posterior-stabilized; mm=millimeters; Std=Standard deviation