

Evaluation of Cadaveric and Synthetic Tibiae for Measuring Tibial Tray Micromotion in Cementless TKA

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INTRODUCTION: Initial fixation of the tibial base in cementless total knee arthroplasty (TKA) is critical for long-term osseointegration [1]. Micromotion at the bone-implant interface has been tied to the quality of bone formation, where shear micromotions of 20–50 μm promote bone ingrowth while micromotions greater than 150 μm lead to fibrous tissue formation [2]. However, it's unclear how these thresholds translate to the osteointegration of tibial trays, which experience both shear and tensile lift-off micromotions. During preclinical testing of new tray designs, safety and efficacy are demonstrated through benchtop comparisons with clinically successful predicate devices in either cadaveric bone with realistic variability but lower bone quality [3,4] or synthetic bone (e.g., Sawbones) that offers standardized mechanical properties [5,6]. Researchers must determine whether it's more realistic to test cadaveric tibiae at lower loads versus evaluating synthetic bones with realistic loads. The research question in this study was whether using cadaveric tibia versus synthetic bones changes the observed micromotion of a clinically successful tibial tray. We hypothesize that the tibial tray would exhibit higher micromotion and increased variability in cadaveric tibia, while synthetic models will show lower micromotion and greater reproducibility.

METHODS: Four cadaveric tibiae (Age 71 ± 8 years; BMI 24 ± 3) were implanted with a commercially available cementless tibial tray by an orthopedic surgeon (BH). Additionally, three synthetic tibial bones (SawboneTM) with 12.5 pcf cancellous cores and 40 pcf cortical shells were implanted with the same trays. Variations in gait (GT) and stair descent (SD) loading conditions were applied to the specimen using a VIVO knee simulator (AMTI), including loading derived from telemetric implants (Case 1) [6] and implant-specific loading derived from a previously published lower-limb finite element model (Case 2) [7]. Variations in load magnitude were evaluated by scaling the AP, SI, VV, and IE load profiles by 75% and 50% in both GT and SD. Each specimen underwent 60 cycles of each activity while micromotion of the implant-bone interface was measured at three locations along the anterior aspect of the tibial tray (lateral, central, and medial) during the 55th cycle (GOM ARAMIS, Fig. 1). The total magnitude of the micromotion was decomposed into lift-off (perpendicular to the resection) and shear (parallel to the resection) and averaged across the measured tray locations. The coefficient of variation (CV) was calculated to compare variability between cadaveric and synthetic specimens. Mean micromotion magnitudes were compared using Welch's t-test, accounting for unequal variances and non-normal distributions in MATLAB (MathWorks).

RESULTS: All cadaveric tibia successfully completed testing at 50% and 75% load levels, but two specimens failed during the 100% loading trials due to posterior subsidence and excessive anterior lift-off. In contrast, all synthetic tibiae completed all loading profiles without failure. Cadaveric and synthetic tibiae demonstrated statistically equivalent mean micromotion magnitudes across load levels of all activities (minimum $p > 0.1$, Fig. 2). More micromotion was observed in cadavers during five of the eight common loading variations. Variability in the measured micromotion was considerably larger in the cadaver group, with CVs ranging between 30%-40% for cadavers and 10%-30% for synthetic bones across all activities. The micromotion magnitude consistently increased with increasing load levels in both groups for all four activities. Increasing from 50% to 75% loading increased the observed micromotion between 9%-26% for cadavers and 21%-45% in synthetic bones, depending on the activity. Lift-off was a greater proportion of the overall micromotion in synthetic bones ($45\% \pm 19\%$) compared to cadavers ($30\% \pm 5\%$), but the differences were not statistically significant.

DISCUSSION: Mean micromotion magnitudes were equivalent between cadavers and synthetic bones, demonstrating that the mechanical properties of the foam bone sufficiently represented the response of a mean cadaver bone. In contrast, cadaveric specimens exhibited considerably more variability, highlighting how variation in bone density influences the observed micromotion. Both models showed increased micromotion with load, but half of the cadaver specimen failed at 100% loading, illustrating the limited strength of retrieved tissue. A limitation of this study is the small sample size, which precluded more detailed statistical analysis. Future work will expand the cohort size and compare alternative implant geometries.

SIGNIFICANCE/CLINICAL RELEVANCE: Synthetic tibiae provide consistency for implant testing, but cadaveric bone exposes the variability surgeons encounter in practice. Recognizing this distinction is critical for interpreting fixation and anticipating clinical performance.

REFERENCES: 1. Bragdon et al., 1996, 2. Pilliar et al., 1986, 3. Miller et al., 2002, 4. Yammine et al., 2020, 5. Bhimji et al. 2014, 6. Navacchia et al., 2018, 7. Maag et al., 2024, 8. Han et al. 2020

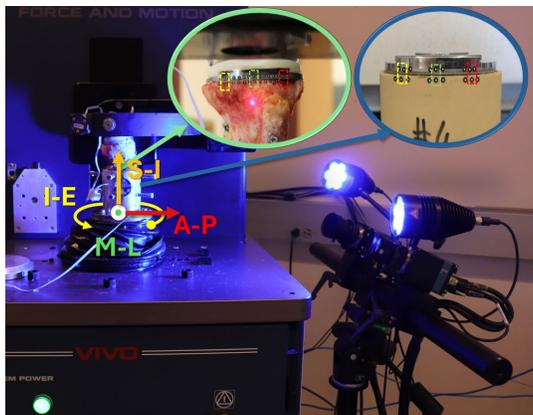


Fig. 1: VIVO simulator with DIC for micromotion measurement. Insets: representative setup for cadaveric tibia (green) and synthetic tibia (blue) with lateral (yellow), central (green) and medial (red) markers.

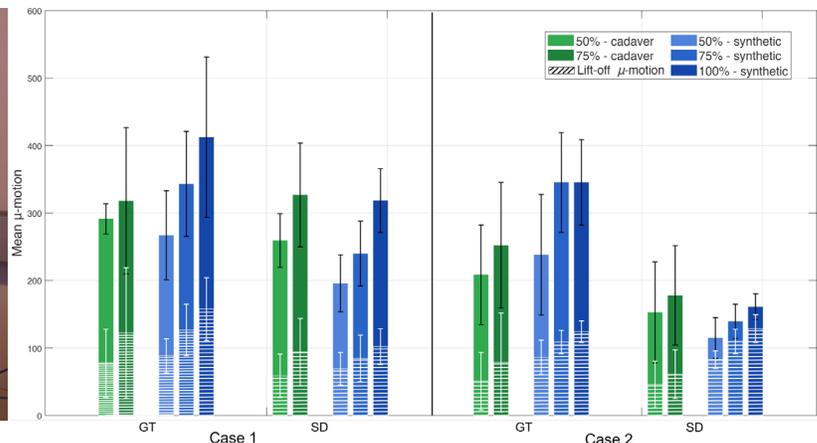


Fig. 2: Mean peak micromotion across cadaveric and synthetic specimen for each loading condition. Cross-hatched regions indicate magnitude of the lift-off component of the micromotion.