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Bending Stiffness in Cadaveric and Composite Long Bones Following Total Joint Replacement

Danielle Gehron
Rose-Hulman Institute of Technology

Anderson Adams MS

Tatsuya Sueyoshi MD

Scott R. Small MS

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Danielle Gehron, Anderson Adams, MS, Tatsuya Sueyoshi, MD

Scott R. Small, MS

Department of Biology and Biomedical Engineering

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ABSTRACT

Several biomechanics studies have utilized commercially available replicate bone models as an alternative to cadaveric tissue specimens, in part due to their ease of handling and reduced expense. In an effort to validate the use of replicate bone specimens in biomechanics research, a number of studies have compared material properties of whole tibia and femur specimens to those of similar cadaveric specimens. Many of these validation studies have ascertained that the material properties of whole bone composite models fall within the range of those properties of cadaveric specimens, while offering reduced interspecimen variability. Current literature lacks, however, the direct comparison between cadaveric and composite specimens after the implantation of joint replacement components. Because of this, the interactions between orthopaedic implant and replicate bone model, and how those interactions compare with those between implants and cadaveric tissue, are relatively unknown. The purpose of this study was to evaluate the use of composite femur specimens in test scenarios aside from the whole-bone instances currently evaluated in the literature. Six cadaveric and six composite tibias and femurs were tested at different stages of surgical intervention. Flexural rigidity was measured using a 4-point bending test as a whole bone, after unicompartimental cut and implantation (UKA), and after total knee cut and implantation (TKA) or total hip arthroplasty (THA). The data did not show a definite trend between tests and specimens but is conclusive enough to use composite models for cadaveric specimens.

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Methods

Six fresh frozen cadaveric femur and tibia specimens were acquired for comparison with six fourth generation medium, left femur and tibia specimens (Models 3401 & 3406, Pacific Research Laboratories, Vashon, WA). Anterior and lateral bending stiffness of the specimens was evaluated between a series of incremental sets in the transition from whole bone to implanted specimen. Femurs were bend tested as whole bones, surgically resected for THA, and after implantation with standard length cementless, collarless femoral stem. Tibias were bend tested as whole bones, surgically resected for UKA, after implantation with a standard sized partial implant, surgically resected TKA, and after implantation of a total knee tibial tray. The bending stiffness of each specimen was measured using a custom built 4-point bending fixture, with 62 mm between successive support and load points, affixed the actuator and baseplate of a benchtop materials testing load frame (ElectroPuls E1000, Instron, Norwood, MA).

Results

Across all trials cadaveric tibias exhibited a mean of 50 Nm^2 lower bending stiffness than composite tibias in anterior testing ($p < 0.0001$) and 56 Nm^2 higher stiffness in cadaveric tibias than composite in lateral testing ($p < 0.0001$) seen in Figure 1. Cadaveric femurs in both lateral and anterior loading exhibited lower stiffness (53 Nm^2 and 22 Nm^2) than composite femurs ($p = 0.0104$) in Figure 2. A significant increase in bending stiffness (0.5 Nm^2 to 25 Nm^2) was observed after each trial in the anterior tibia test ($p = 0.0015$), with similar, yet non-significant trends in lateral tibia and both femur tests ($p = 0.3836$). In anterior tibia testing, a statistically significant difference in bending stiffness was observed between the tibia resected for UKA and the intact tibia ($p=0.027$). In lateral tibia testing, the difference in bending stiffness between the intact tibia, the tibia resected for a UKA and implanted UKA is statistically significant ($p = 0.0376$ and $p = 0.0438$). In anterior femur testing, a statistically significant difference was observed between intact and implanted femur ($p = 0.0211$). In lateral femur testing, intact and implanted femurs show a statistically significant difference ($p = 0.0048$).

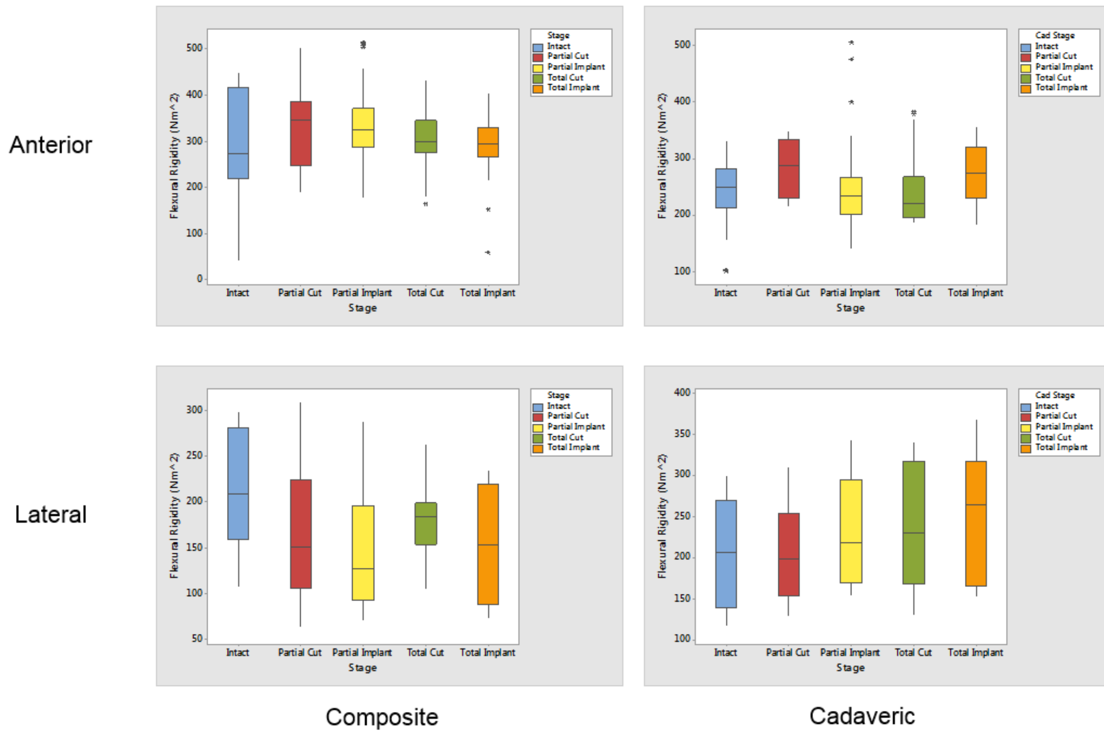

Figure 1. Flexural rigidity means of the composite cadaveric tibias during surgical intervention in anterior and lateral testing.

Within composite femurs, there was a statistically significant decrease in bending stiffness between the intact and cut specimens in both anterior ($p = 0.012$) and lateral ($p < 0.001$) bending tests. Conversely, cadaveric bones significantly increased in anterior ($p < 0.001$) and lateral ($p < 0.001$) bending stiffness when cut and surgically prepared for an implant. The variance for composite whole femurs in both directions was found to be 7 to 18 times smaller than of cadaveric bone, consistent with prior validations of composite femurs.

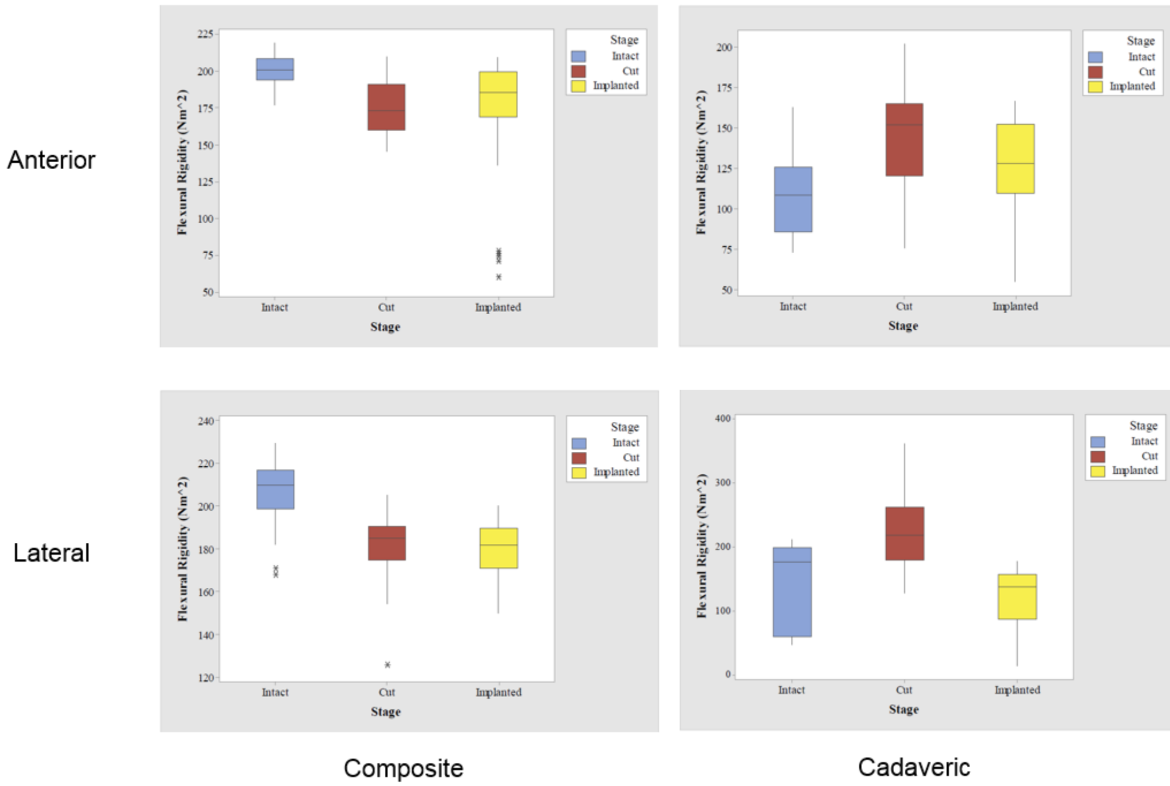

Figure 2. Flexural rigidity means of the composite cadaveric femurs during surgical intervention in anterior and lateral testing. (Anderson Adams, 2015)

Discussion

At most stages of surgical resection and implantation, there was little continuity between cadaveric and composite bone specimens. From this testing we were not able to differentiate a clear pattern in the change in bending stiffness between the whole, resected, and implanted conditions of the cadaveric and composite tibia and femur specimens. Prior studies have exhibited reduced interspecimen variability in whole bone composite specimens compared with their cadaveric counterparts. Trends of this reduced variability was observed in the current study for whole bone specimens, however, the complex nature of the implanted specimens lead to increased variability in both the composite and cadaveric scenarios. Further analysis is needed to finalize conclusions regarding the effectiveness in which implanted composite bones mimic cadaveric specimens.