The Influence of Bone Resection Depth on Tibial Loading

INTRODUCTION:
While long-term success in primary total knee arthroplasty (TKA) is high, aseptic loosening, subsidence, and tibial collapse remain as factors in tibial component revision. Prosthetic alignment, patient characteristics and implant design are all important factors in long-term survival of TKA, yet the level at which each of these factors contribute to implant loosening has not been fully described. The purpose of this study was to investigate the influence of bone resection depth on proximal tibial loading.

METHODS:
Three-dimensional models of 3rd generation composite tibiae (Medium, Left Tibia, Model 2150, Pacific Research Laboratories, Inc., Vashon, WA) were generated from CT scans using MIMICS medical imaging software (Version 13.0, Materialise, Belgium). All tibia models consisted of homogeneous, isotropic material properties for each of the two layers (E\sub{cancellous} = 7.6 GPa, E\sub{composite} = 104 MPa) within the composite tibia as specified by the manufacturer. The mesh and material property assignments were exported to ANSYS (Version 11.0, Canonsburg, PA) for analysis. Convergence tests and validation experiments were conducted to ensure the accuracy and validity of the models.

Bone resection models were generated with 5- and 15-mm of resection beneath the joint line with 0 degrees of posterior slope. Depths of resection were chosen to reflect resection depth extremes based on knee deformity and bone quality observed clinically and are consistent with resection levels examined in previous studies.

The resected tibia models were implanted with metal-backed TKA tibial components (Biomet Inc., Warsaw, IN). Based on surgeon guidance, size 75-mm tibial components were implanted into models with 5-mm of bone resection, which were matched with 70-mm femoral components for loading. Size 63-mm tibial components were implanted in models with 15-mm of bone resection and matched with 60-mm femoral components. Polyethylene bearing inserts of 10-mm thickness were matched with metal trays. All implant materials were modeled as homogeneous, isotropic materials (E\sub{polyethylene} = 230 GPa, E\sub{metal} = 500 MPa, E\sub{composite} = 2.28 GPa). The femoral component was positioned at 0° of flexion, with model contact areas verified through experimental contact analysis between manufactured femoral and tibial bearing components.

The implanted tibia models were analyzed under axial compression. Static loads of 2700 N were applied through the femoral component in a balanced 50:50 (medial:lateral) distribution and a medially skewed 80:20 distribution to simulate varus loading. The distal 150-mm of the tibia was constrained against motion in all directions.

RESULTS:
To evaluate tibial loading, the strains were evaluated in the proximal 3-cm of the tibia, where tibial collapse is most likely. Furthermore, the tibia was circumferentially divided into 24 measurement regions. The delineated measurement regions are shown in Figure 1.

In balanced 50:50 loading, the highest strain values were observed in the posterior regions of the tibia regardless of resection depth (Figure 2). Increased resection depth resulted in increased strain in all posterior measurement regions. It was noted that a 5-mm resection depth resulted in a smaller range of strains across all regions (1600 µε vs 2500 µε), i.e. the 5-mm resection depth had a more uniform strain distribution.

In simulated varus loading, the highest strains were also observed in the posterior region and similar trends were observed for anterior and posterior behavior as compared to the balanced loading scenario. The 5-mm resection depth still resulted in a smaller range of strains (1800 µε vs 2800 µε). Strains for the AMP, AMC, and ALC regions were much greater than the strains for the balanced loading. The strains in the ALP regions for the valgus loading were approximately one-half the strains for the balanced load. An increased resection depth also resulted in increased posterior strains in all regions, with the PLP regions experiencing the greatest increase in strain. Within the PLP regions, the strain in the 0-1 cm region (i.e. on the periphery) increased approximately 200% when compared to the 5-mm resection depth for the same varus loading.

DISCUSSION:
Significantly higher strains were observed across a majority of the posterior tibia measurement regions for both loading scenarios as the resection depth increased. Peripheral anterior strains increased with an increased resection depth. This posterior and peripheral shift may be correlated to both the greater medial relative to lateral reduction of tibial plateau surface area with increased resection depth, in addition to the posterior shift in component stem placement required for implantation in a 15-mm resected tibia.

Despite the experimental validation and clinical correlation of the results of this study, there are limitations to the present study. Composite tibiae have been used extensively in biomechanical studies, but it would be advantageous to consider a cadaveric specimen. The results of this study were validated with previous photoelastic coating experiments, but the model would be strengthened with comparison to strain gauge data. Inclusion of additional resection depths may also provide insight into the research question.

SIGNIFICANCE:
Prior clinical and biomechanical studies have indicated tibial overload as a cause of early TKA revision. Increased tibial resection depth may contribute to increased posterior and peripheral strain, particularly in the case of increased varus loading, in an area most susceptible to bony failure and early aseptic loosening.

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