

Augmented Symmetrical Cones Outperform Asymmetrical Cones in Osteoporotic Tibial Defects: A Biomechanical Analysis of Implant Stability and Bone Overload

Yi Ren ^{1*}, Chloe EH Scott ^{2,3}, Shuqiao Xie ⁴, Pankaj Pankaj ¹

¹Institute for Bioengineering, School of Engineering, The University of Edinburgh, UK

²Edinburgh Orthopaedics, Royal Infirmary of Edinburgh, Edinburgh, UK

³College of Medicine and Veterinary Medicine, The University of Edinburgh, UK

⁴Department of Bioengineering, Imperial College London, UK

*Presenting author's email: yi.ren@ed.ac.uk

Disclosures: Yi Ren (N), Chloe EH Scott (N), Shuqiao Xie (N), Pankaj Pankaj (N)

INTRODUCTION: When managing large medial tibial defects in total knee arthroplasty (TKA), surgeons face a critical choice: bridging the defect with an asymmetrical cone or anatomically reconstructing it with an augment and a symmetrical cone. However, a lack of clear biomechanical evidence exists to guide this decision, particularly in compromised osteoporotic bone where implant stability is paramount. Furthermore, failure can occur through distinct pathways—either via excessive micromotion leading to aseptic loosening or through periprosthetic bone overload risking fracture—and it is unclear how different surgical strategies influence these risks under various daily activities. This study aimed to resolve this clinical uncertainty by comparing the biomechanical performance of these two strategies in both healthy and severely osteoporotic bone.

METHODS: This study compared two surgical strategies by analyzing 16 finite element configurations, derived from two primary models (2 strategies × 2 bone qualities × 4 loading scenarios). The models simulated a synthetic medium-sized tibia with a large, uncontained AORI Type 2a medial defect (Fig. 1a): one treated with an asymmetrical cone (Asy) and the other with a symmetrical cone and a medial augment (Aug). Severe osteoporosis (OP) was simulated by reducing cortical and cancellous bone Young's moduli to 40% and 28% of healthy values, respectively. Both healthy and osteoporotic models were subjected to four physiological loading scenarios: standing up (SU), walking (WA), knee bending (KB), and stair descending (SD) (Fig. 1b). Implant stability was assessed by quantifying micromotion at the bone-coating interface under full loading cycles. Bone response was evaluated by calculating the volume of cancellous bone exceeding established yield strain thresholds (> 0.5% for tension or < -0.7% for compression) at the timepoint of maximum overload within each cycle.

RESULTS: In healthy bone, both strategies in different scenarios provided adequate stability, with the micromotion at about 99% contact area remaining below 50 μm threshold for osseointegration and long-term stability (Fig. 2). In osteoporotic bone, however, their performance diverged significantly. The stability of the asymmetrical cone was severely compromised, with peak micromotion under WA and SD loads increasing to 97 μm and 91 μm, respectively. Critically, approximately 5% of the bone-implant interface exceeded the 50 μm threshold during WA. In stark contrast, the augmented symmetrical cone maintained robust stability with less than 1% of its interface area exceeding the safe limit. This heightened instability translated directly to bone overload: the overloaded bone volume for the asymmetrical cone reached 4.2% during osteoporotic SD, a 20% increase over the 3.5% observed for the augmented construct (Fig. 3).

DISCUSSION: Our findings reveal a critical biomechanical principle: the asymmetrical cone acts as a cantilever. While tenable in healthy bone, this mechanism fails under gait-induced bending moments in compliant, osteoporotic bone. In contrast, the augmented reconstruction creates a direct load transfer column, preventing cantilever collapse. This mitigates excessive micromotion (risking aseptic loosening) and extensive bone overload (risking subsidence or fracture). Notably, the analysis revealed activity-dependent failure pathways: walking generated the most widespread instability (micromotion), while stair descending caused the highest bone overload (strain).

SIGNIFICANCE/CLINICAL RELEVANCE: For surgeons treating large medial tibial defects, this study provides a clear, evidence-based recommendation: while an asymmetrical cone may be a viable option in patients with good bone quality, anatomically reconstructing the defect with an augment and symmetrical cone is a mechanically superior and safer strategy in any patient with suspected or confirmed osteoporosis to ensure stable long-term fixation.

ACKNOWLEDGEMENTS: The authors would like to thank Stryker Orthopaedics for providing the CAE models of the tibial components used in this study.

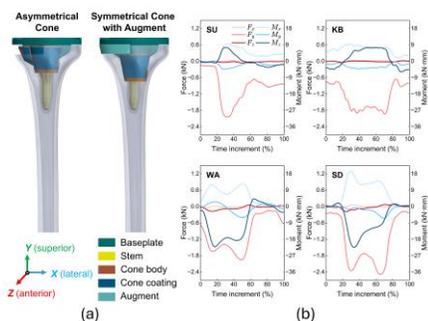


Fig. 1. (a) Finite element models comparing the asymmetrical cone (defect-bridging) and augmented symmetrical cone (anatomical reconstruction) strategies. (b) The four simulated loading scenarios: standing up (SU), knee bending (KB), walking (WA), and stair descending (SD).

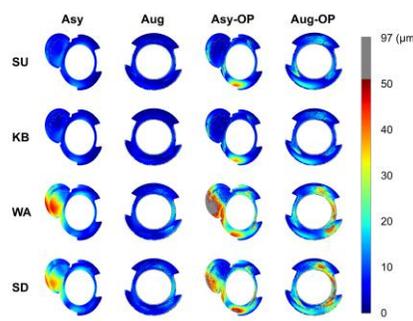


Fig. 2. Micromotion contours at the bone-coating interface for osteoporotic models. The asymmetrical cone shows widespread regions of high micromotion (> 50 μm, shown in gray) during walking (WA), while the augmented cone maintains stability.

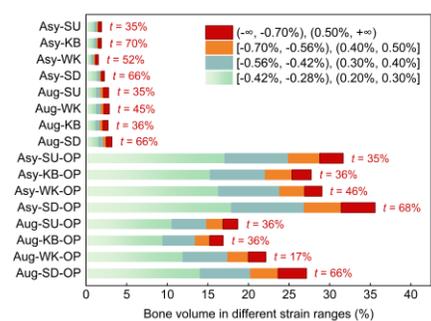


Fig. 3. Cancellous bone volume distribution by strain range at the timepoint (*t*) with peak load. Red segments indicate volume exceeding yield thresholds. During stair descending (SD) in the osteoporotic model, the asymmetrical cone resulted in a 20% greater overloaded bone volume than the augmented construct.