Computational Analysis on Post-Fusion Effects of Hardware Preservation of Removal on Proximal Tibia Cartilage and Subchondral Bone

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INTRODUCTION: Proximal tibia fractures require screws to be applied to the fracture site for proper fusion to occur without misalignment, at which point it is at the surgeon's discretion whether or not to remove the hardware. Literature is inconclusive if removal would benefit the patient.[1-3] Complications from both screw removal and non-removal are reported; screws carry the risk of migration and proliferating microfractures, whereas removal may compromise bone integrity.[4-7] Through computational analysis, this study investigates the effects of screw removal at the proximal tibia site and its effect on the biomechanics of articular cartilage and surrounding tissue to better assist the surgeon's decision to remove hardware post-fusion.

METHODOLOGY: A generic bone model was used for this study, and its 3D geometry was reconstructed with Mimics and 3-Matic (Materialise, Belgium). The bone was modeled as composed of both cortical and cancellous bone, whose mechanical properties were taken from previous studies.[7] On the two tibia condyles, a layer of 3mm of articular cartilage was added and modeled as a biphasic material.[8] A total of four scenarios were simulated: intact tibia (I), tibia with titanium screws (S), tibia with holes (H), and tibia with holes filled with calcium sulfate polymer (P), see figure 1. The screws were inserted in the subchondral bone as per indications of a surgeon. A mechanical load simulating the gait of a 70 kg person was applied to the bone model, and a computational analysis was conducted with FEBio Suite (University of Utah) to yield stresses in the cartilage and subchondral bone.[9]

RESULTS: Effective fluid pressure and effective stress in the cartilage were identical among the models (data not shown). In contrast, the effective stress in the subchondral bone changed according to the simulated scenario, see figure 2. The intact tibia produced a peak stress of 1.90 MPa. The holes induced the largest stress peak of 2.74 MPa, concentrated at the cortical/cancellous interface at the holes sites, suggesting that holes compromise the integrity of the bone. Screws induced the next highest stress at 2.14 MPa, concentrated in the cortical bone at the screw sites, and where the cancellous bone contacts the edge of the screw's thread. The calcium sulfate polymer most closely resembled the stresses seen in the intact tibia; it induced a peak stress of 2.03 MPa at the cortical/cancellous interface at the polymer site.

DISCUSSION: The results of this study suggest that cartilage may not be directly affected by the geometric and mechanical alterations that screws cause in the bone. Different outcomes are observed in the subchondral bone. It is observed that screw holes produce higher levels of mechanical stress at the cortical/cancellous interface when compared to those scenarios including the presence of screws or polymer filling. This is because both cortical and cancellous bones tend to collapse at the screw holes thus increasing the Lagrange strains (data not shown). In contrast, when holes are filled with polymer whose mechanical properties are similar to that of cancellous bone, stresses in the subchondral bone most closely match those found in the intact tibia scenario.

SIGNIFICANCE: This study suggests that post-fracture cartilage complications such as osteoarthritis may not be directly caused by the presence or absence of the hardware in the tibia. Also, aimed at preserving subchondral bone integrity, hardware removal post-fracture fusion should be accompanied by filling the holes with polymer whose mechanical properties resemble those of the natural cancellous bone.

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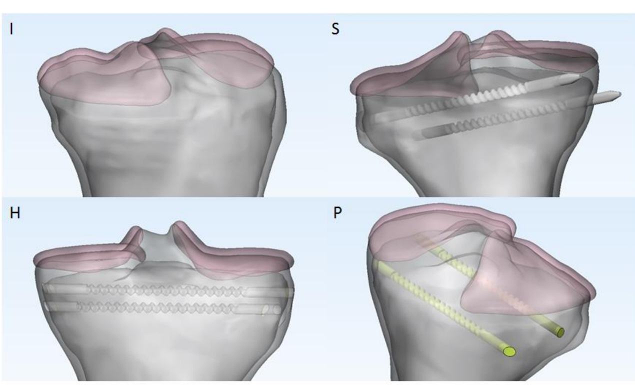

Figure 1: Models of the generic bone with cancellous bone, cortical bone, and cartilage as seen in Mimics' 3-matic. **(I)** The intact tibia (**S)** The tibia with titanium screws implanted into the proximal head. **(H)** The tibia with the screws removed, unfilled. **(P)** The holes filled with a calcium sulfate polymer.

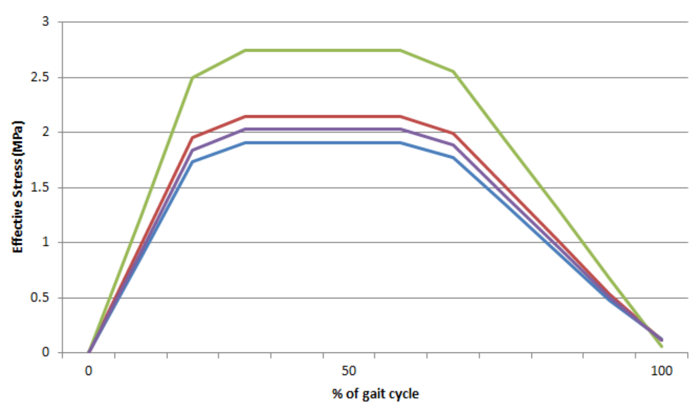

Figure 2: Peak effective stress in the proximal head over normal gait. (**Blue**) Intact tibia. **(Red)** Titanium screws. (**Green**) Unfilled holes. (**Orange**) Holes filled with a calcium sulfate polymer.