A Validated FE Model for Proximal Tibia Bone Grafting: The Study of the Effect of Window Size on Tibia Stability and Mechanics

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Introduction: Bone grafts have been increasingly harvested by different specialties for a wide range of indications. Currently, the most frequently used site for harvesting is the iliac crest. However, complication rate for this procedure has been reported to be as high as 10%(1). The Proximal tibia has been in recent years proposed as an alternative site for bone graft harvesting, with reported lower complication rates and an adequate quantity of cancellous bone. Despite this, the effects of proximal tibia bone grafting on the bone’s stability and mechanical strength post-surgery are not well understood. The amount of cancellous bone to be harvested from the site is largely dependent on the size of the cortical window introduced via osteotomy onto the proximal tibia (2). The aim of this study is to investigate the effect of large cortical window sizes introduced at the proximal tibia bone grafting site through a validated finite element model.

Methods: 2 cadaveric tibiae were obtained with no history of bone disease, using DEXA to assess bone quality. The 2 tibiae were experimentally tested under mechanical loading using an MTS 858 Bionix under 3 times body weight by a custom femoral component designed to replicate physiological loading conditions at the knee under normal walking. Strain rosettes were attached at specified locations on the tibia at three different levels on anterior, medial, lateral and posterior aspects to record strain data for finite element model validation. The tibiae were harvested for cancellous bone using a standard surgical technique (2,3) with a 10mm circular osteotomy and mechanical testing was repeated. The size of the osteotomy was enlarged and mechanical testing repeated in increments of 2.5mm up to a maximum window size diameter of 25mm (Fig 1a). Finite Element Models were created from Computed Tomography scans of the selected intact and harvested tibia using Mimics Software (Materialise NV, Belgium) and the models were simulated with loading and boundary conditions similar to those described experimentally. One model was created for the intact condition and each window size for a total of 16 models (for 2 tibiae). Principal strain values calculated from the experimental results were used to validate the Finite Element Models (Fig 1b).

Results: The specimens did not fail during experimental testing. A total of 16 FE simulations were conducted. In general, the models agreed well with experimental data with acceptable accuracy, with a mean regression of 0.857 and Principal Strain Root Mean Square Error Percentage (RMSE %) of 20%. (Fig 2) The simulation results showed that at hole sizes above 17.5mm, the load response of the harvested tibia to the loads applied at the knee changed significantly when compared to smaller hole sizes; this was
accompanied by an observable deformation of the window, which suggests a possible point of failure. No critical yield strain values for bone were observed in the various models.

**Discussion:** Larger bone graft volumes can be obtained from the tibia with larger cortical window sizes. Experimental and simulation results suggest that the tibia is able to sustain normal walking loads even with cortical defects up to 25mm in size. However, such a large window size is not clinically feasible. In addition, the deformation of the window observed in the simulations suggests that cortical window sizes not exceed 17.5mm should be recommended. No soft tissue effects were considered in this experiment, but these are not expected to alter the findings significantly. More study is needed to ascertain the effects of repeated loading and fatigue on the harvested tibia.

**Significance:** The development of a validated Finite Element Model for bone grafting has considerable value for reducing the costs in studying and optimizing the outcomes of bone graft surgery. Current results suggest that current surgical practice is conservative and bone graft windows up to 17.5mm may be safe for clinical practice, provided given strict patient cooperation of restricted weight bearing and avoiding vigorous activity.

![Fig1: From Left : Fig 1a: Experimental Setup. Fig 1b: FEA model of harvested tibia](image)
Fig 2: Validation of the 16 FEA models, showing average regression, gradient and intercept of the 1 models.