Validating a computational model to determine optimal screw configuration for plate of fixation of tibial fractures

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INTRODUCTION: While implanting tibial plates at fracture sites, it is at the surgeon's discretion the number and configuration of screws that should be implanted into the plate. However, there lacks sufficient research on the subject regarding how different screw configurations would affect the stresses seen throughout the implants and bone. Using computation analysis of models validated with in-vitro experiments, this study will impart how three different screw configurations affects the stresses seen throughout the plate and in the screws. This information is imperative to understand how mechanical stability relates to mechanical fatigue, and to provide surgeons with the necessary information for them to implant the correct number of screws to insure mechanical stability as well as reduce the risk of complication from mechanical failure of the screws.[1,2]

METHODS: To validated the predictions of the computational model, in-vitro biomechanical experiments were conducted on Sawbones Generation IV human tibia models (n=4), see Fig 1a. The bone phantoms were transversally cut at the mid diaphysis. Subsequently, 8 hole straight 4.5 mm plates (DePuy Synthes, Wet Chester, PA) were applied to the lateral side of the bones, and fixed with screws applied in locked mode. The models were mounted on a testing block, locked at the distal end and axially compressed via a universal joint mounted on a MTS 858 Mini Bionix II testing system (MTS Systems Corp., Eden Prairie, MN). Compression was performed in load control. Physiological loading conditions were implemented: the load ranged from 0 N to 1000 N, and was applied in the direction of the mechanical axis of the bone. Infrared markers were applied on the distal and proximal parts of the models to track relative bone motion (MaxPro tracking system, Innnovision, Marietta, GA). For each model, 3 configurations were evaluated: all screws locked in (8screws), screws 1,4, 5 and 8 (1458screws), and screws 1,3, 6 and 8 (1368screws).
A finite element model representative of the bone models tested in-vitro was generated. The geometry of the computational domain was reconstructed via MIMICS (Materialize, Leuven, Belgium) and included cortical and cancellous bone, and hardware. Materials properties were taken from previous studies [3]. Computations were performed via FEBio (University of Utah). The model was validated by comparing its predicted relative range of motion (ROM) of distal vs. proximal tibia. Subsequently, a stress analysis on the hardware was carried out.

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RESULTS: The relative ROM was evaluated as the angle between the axes of the distal and proximal portions of the tibia in the 3 major anatomical planes (sagittal, axial and coronal). Experimental data indicated that the relative ROMs in the axial and sagittal planes were not statistically significant (data not shown). In the coronal plane, model's predictions were in good agreement with the experimental data, see Fig 1b-d. Maximum Von Mises stress values at the screws and plate, for all the constructs investigated, are reported in Table 1. The highest stress of 15.2 MPa was seen in the 8screw configuration at the seventh screw. The 1458screws was the next highest at 7.5 MPa, and the 1368screws was the lowest at 5.8 MPa. The higher stresses were observed at the screws ventral to the fracture, at the bone-screw interface. The 8screws also saw the highest stresses in the plate. Stress distribution in the hardware for the 3 constructs investigated is reported in Fig 2.

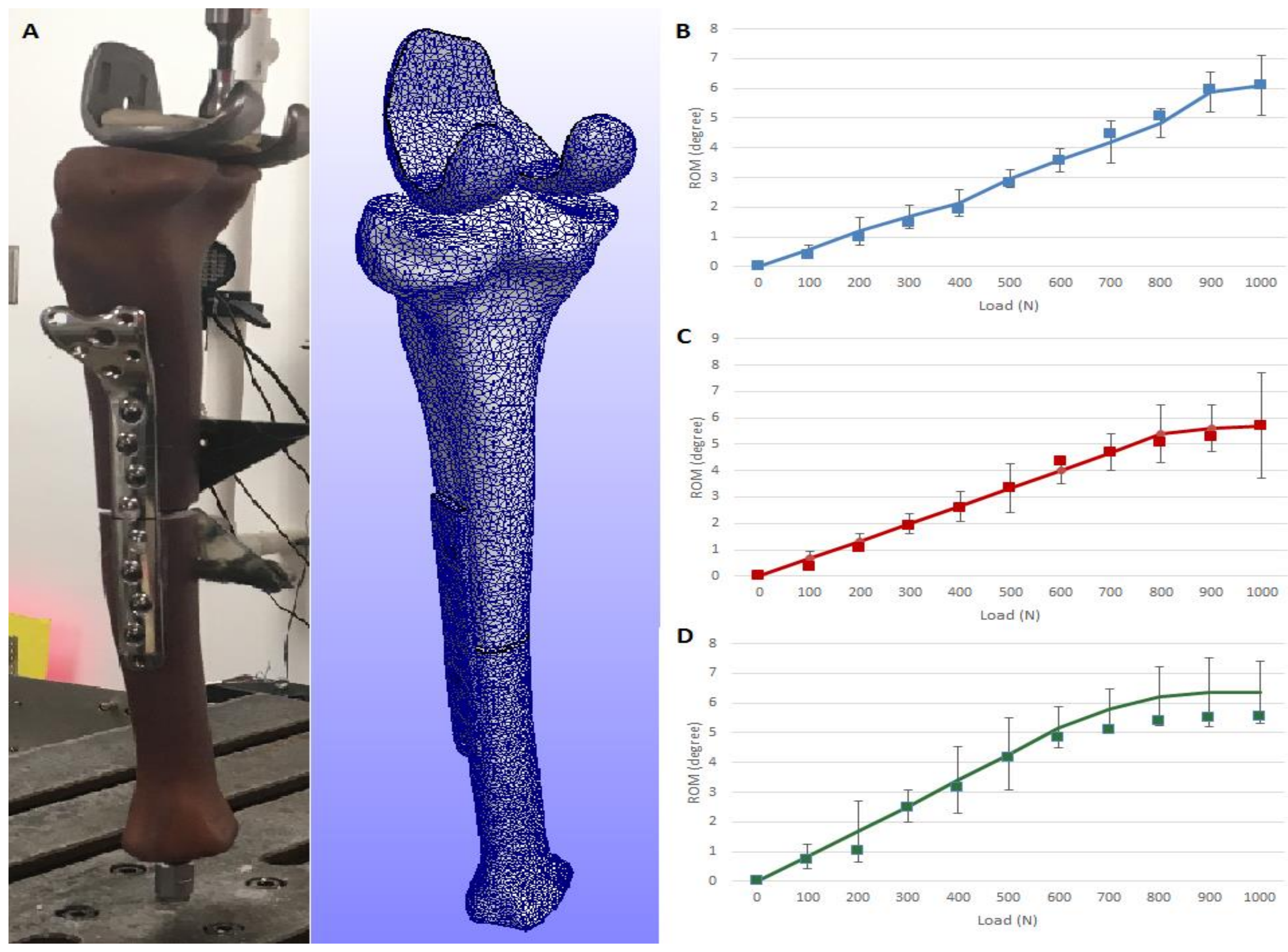

Figure 1: (a) The sawbone and FEM. (b-d) The coronal angulation of the practical (squares) and FEM (line) model with standard deviation. (b) 8screws, (c) 1458screws, and (d) 1368screws.

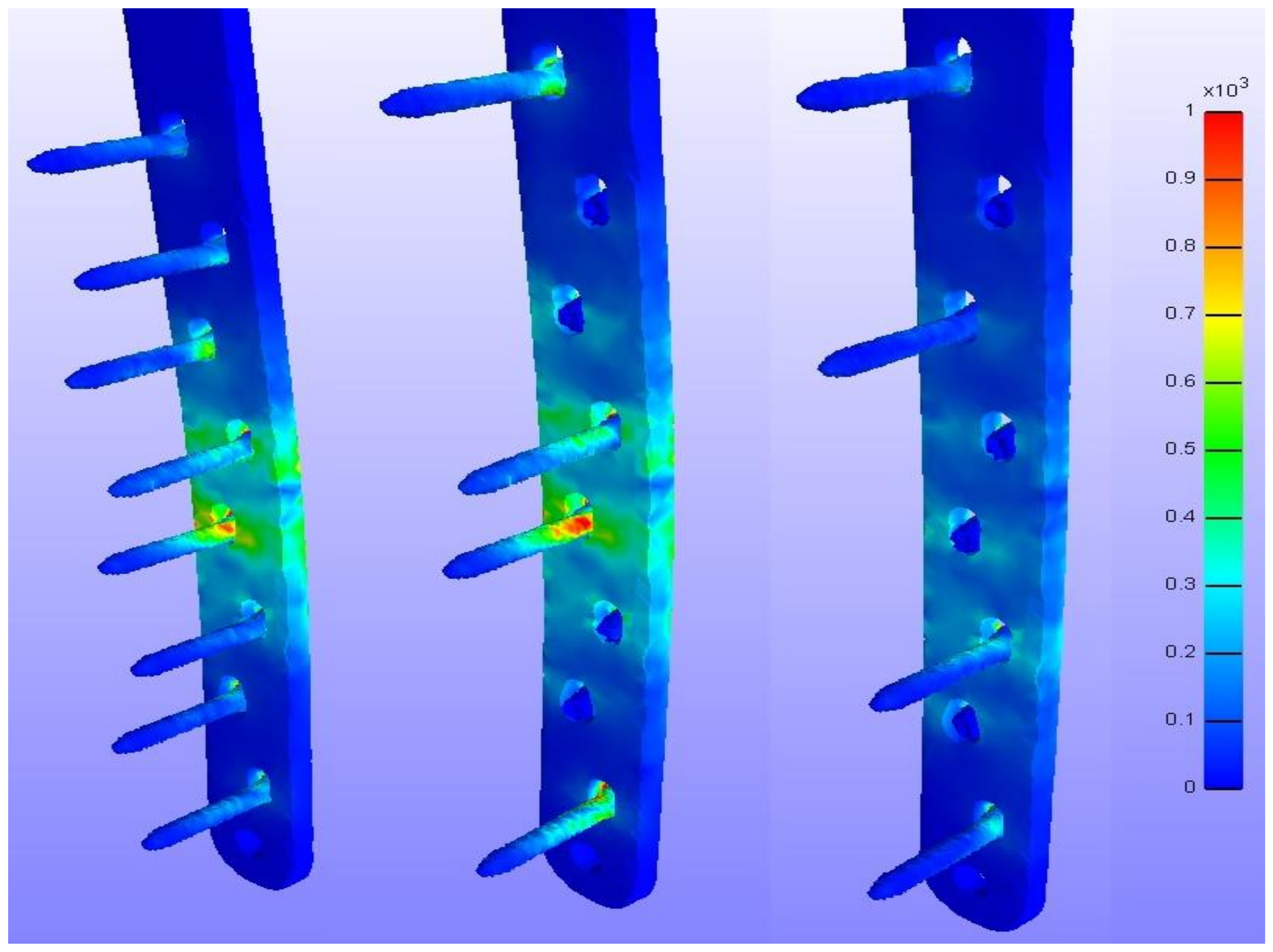

Figure 2: The stress profile of the three configurations.

DISCUSSION: A finite elemental model was generated to investigate the effects screw configurations had on structural integrity of the plate and screws. The accuracy of model's calculations was successfully validated by comparing its predictions to experimental data from an in-vitro biomechanical test. The stress profiles suggest that the areas most at risk for failure are the screws closest to the fracture site, as well as the heads of the screws. Applying different configurations of screws could reduce the stress seen on the plate and screws and reduce the risk of failure. The 1458screws would be the optimal configuration, as they exhibit a significantly lower stress than the 8screws, but is more mechanically stable than the 1368 screws. However, this study does not observe how the configurations would affect the bone itself and its regenerative process due to soft tissue being omitted at the fracture sight.

SIGNIFICANCE: Different screw configuration evoke significantly different stresses throughout the plate and at the screws. It is important for the surgeon to understand how each screw configuration would affect the implants, as this would reduce the risk of complications for the patient and mechanical failure of the plate and screws.

REFERENCES: [1] Muller, et al. Man of Int Fixation, 1995 [2] Greiwe, et al. Locking Plate Tech, 2007 [3] Mirzaali, et al. Bone, vol 93. 2016

	8screws	1,4,5,8	1,3,6,8
screw1	0.3	3.6	1.4
screw2	1.2	N/A	N/A
screw3	4.4	N/A	1.3
screw4	4.3	4.8	N/A
screw5	7.9	7.5	N/A
screw6	3.3	N/A	5.8
screw7	15	N/A	N/A
screw8	2.6	5.2	2.9
plate	8.0	7.5	3.0

Table 1: Maximum Von Mises stresses at screws and plate (MPa)