

Validation of Finite Element Modeling of Diaphyseal Bridge Plate Fracture Fixation

Zachary Koroneos¹, Hwabok Wee PhD¹, Shaun Manatt, J. Spence Reid MD¹, Gregory S. Lewis PhD¹

¹Penn State College of Medicine – Department of Orthopaedics and Rehabilitation
Email: zqk5040@psu.edu

Disclosures: Zachary Koroneos (N), Hwabok Wee (N), Shaun Manatt (N), Spence Reid (J&J Depuy-Synthes; Osteocentric), Gregory Lewis (N)

INTRODUCTION:

Bridge plating is often performed in the repair of long bone fractures to stabilize two disconnected fragments and allow for secondary bone healing. Across the literature, working length (distance between the two innermost screws on either side of the fracture) has been determined to be a key factor in the rigidity of locking plate constructs, with shorter working lengths providing stiffer constructs. There have been studies that simulate bridge plate constructs and have evaluated parameters such as working length; however, few have been validated with physical testing raising concerns of model credibility¹⁻³. The purpose of this study was to develop finite element models of simplified bridge plate fixation with varying inner working length and to compare simulated results to corresponding experiments when applying independent axial and torsional loads.

METHODS: Experimental Tests: Nine straight tubular synthetic bones (composite Sawbones 3403-10) with geometry based on typical femur diaphyseal dimensions (OD 27 mm, ID 12 mm) were cut such that a 25 mm gap was created in the center to represent a segmental defect or non-load bearing comminution (Fig. 1). Three different construct groups with varying screw positions in a 14-hole generic plate were tested, including: long working length (189 mm); middle working-length (120 mm); and short working length (52 mm) with the numbers corresponding to the constructs in Fig. 1. The plates were stainless steel with a cross-section of 3 mm x 12 mm and an area moment of inertia that was similar to common commercial plates. There was a 1 mm offset between the plate and bone by using a stainless-steel shim upon application. Constructs were tested in a hydraulic actuator in both compression (up to 400 N) and torsion (up to 8 Nm) independently. The compression setup applied compression through a spherical joint in line with the bone axis, which induced simultaneous bending in the plate. The torsion setup involved transverse planar bearings at the proximal end with the aim of applying a pure torque. Reflective markers for 3-D motion capture data were placed on the bones at both sides of the fracture gap, both bone ends, and on the actuator arm. The positions of these markers were tracked using a 4-camera system (Motion Analysis), and interfragmentary kinematics across the fracture gap were calculated using appropriate coordinate transforms. Using the known coordinates of the markers relative to the points at the edge of the bone at the gap, a least squares transformation. The 3-point clusters were used to determine the coordinate system being used.

Finite element (FE) simulations: FE model constructs were created in Abaqus (Dassault Systèmes) to replicate geometries, materials, and interactions present in the experiments. Plates and screws were modeled as linear elastic isotropic. Bone properties were anisotropic and were obtained from Sawbones. The plate modulus was calibrated through 3-point bending tests ($E = 191$ GPa, $\nu = 0.3$). The screws were modeled as cylinders with tie constraints to the holes in the bone. Boundary conditions corresponding to the fixture ends in the experiment were implemented through reference points connected to the bone ends with coupling constraints. Frictional contact at the middle of the plate where plate-bone contact occurred used coefficients from the literature and contact controls in Abaqus. Mesh convergence was performed and converged within 5% of the finest model with approximately 220,000 elements. Interfragmentary motion was calculated as relative displacement of a standardized point pair crossing the fracture gap at the far cortex.

RESULTS: A good agreement was found between the FE model and the corresponding experiments for the interfragmentary motion (Fig. 2.). The FE model results demonstrated similar trends as the corresponding experiments for both axial compression and torsion. In both FE model and experiments, the middle working-length had the most interfragmentary shear displacement in torsion and the long working length had the most interfragmentary axial displacement in compression. There was little shear displacement in compression tests and little axial displacement in torsion tests.

DISCUSSION: Experimental results supported credibility of the FE model under three different configurations and two modes of loading. The short working-length constructs resulted in the lowest interfragmentary motion for both compression and torsion, supporting the findings of previous studies. Also as expected, in both the torsional simulations and experiments, the long working length had the most interfragmentary shear displacement. But interestingly, under compression the middle working length produced the largest axial displacements. This was likely due to the long working-length allowing for early contact between the plate and bone ends at the gap site, reducing effective working length. This relationship between plate-to-bone contact at the gap has not yet been reported and the relationship was found in both experimental and validated models. The effect of working length was more pronounced in torsion than bending, and higher shear displacements were observed in these models than axial displacements in bending. Furthermore, the plate-bone contact that occurs with bending does not occur in torsion due to the difference in displacements. Simulations used idealized boundary conditions and linear elastic material behaviors. Current work involves using commercial plates in the validated FE model and testing more parameters that may affect the plate-bone contact relationship under similar loading.

SIGNIFICANCE/CLINICAL RELEVANCE: Biomechanics of bridge plating plays an important role in the clinical outcomes of patients regarding post-operative healing and stability. This study develops and assesses the validity of a computational model to enable visualization and prediction of these fundamental biomechanics.

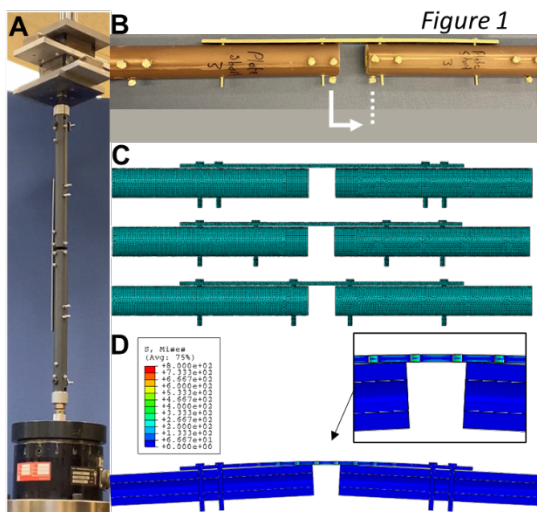


Figure 1. Experimental testing setup for torsion (A), and short working length construct with synthetic bone, plate, screws and reflective motion capture markers (B). Simulation models of three constructs (C), and results for long working length with inset image showing plate-bone contact (D).

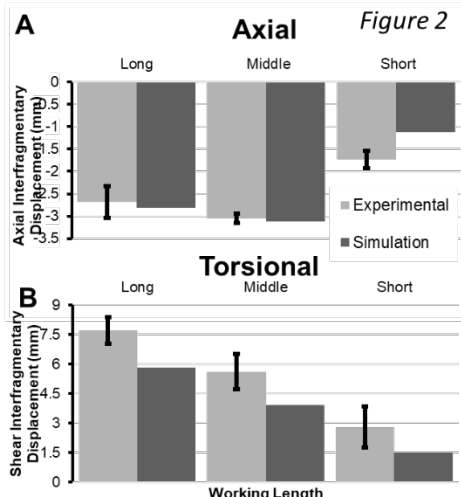


Figure 2. Interfragmentary axial displacement under axial loading (150 N) (A), and Interfragmentary shear displacement under torsional loading (6 Nm) (B). Error bars represent standard deviation.

ACKNOWLEDGEMENTS:

Funding from National Institute of Biomedical Imaging and Bioengineering (1R01EB029207)

References:

- [1] Wee, H et al., (2017) Ann. Biomed. Eng. 45(3):668-680
- [2] Stoffel, K. et al., (2003) Nov;34 Suppl 2:B11-9
- [3] MacLeod, A. et al, (2018) June;18, Injury