Estimating Micromotion in Distal Femur Fracture Reconstructions: A Lightweight Computational Framework

Michael W. Hast, PhD
Elaine C. Schmidt, MS
Samir Mehta, MD
Josh R. Baxter, PhD

Department of Orthopaedic Surgery, University of Pennsylvania

Summary

Controlled micromotion between bone fragments is a vital component of fracture healing. The functional stiffness of a distal femur locking platesis altered by implant geometry, material, and bridge span (the distance between screws crossing the fracture line). Loads applied to the implant are directly affected by the location of the fracture along the femur. Surgeons currently rely upon anecdotal experience to create dynamic reconstructions that encourage bone healing. This paper outlines a lightweight computational modelling technique that estimates implant deflection during walking. The algorithm accounts for changes in fracture location, bridge span, and material properties of the implant. Preoperative utilization of this modelling paradigm could potentially improve a surgeon's "best guess" to optimize the mechanical environment for callus formation to occur.

Introduction

Distal femoral fractures are debilitating injuries that typically require surgical intervention to repair. Bridge plating of distal femoral fractures is an inexact science, with high reoperation rates.[1] The purpose of this study was to develop a lightweight computational algorithm capable of estimating displacements between bone fragments. We developed a paradigm using a musculoskeletal model in conjunction with uniform beam theory assessments to make estimations of implant deflections and interfragmentary displacements. We hypothesized that this model would provide reasonable approximations of implant deflection with minimal computational time.

Methods

A musculoskeletal model of a walking 50th percentile male was used in the study (Figure 1A).[2] The right femur was split and reconstructed with a weld joint between 50-90% of the length of the femur. Muscle forces during walking were estimated using the on-board static optimization algorithm. Joint reaction forces and moments were calculated at the weld joint (Figure 1B). Estimations of plate bending were performed using Euler–Bernoulli uniform beam theory (Figure 1C).[3] Implants were represented as simply supported stainless steel or titanium rectangular bars (W: 18mm x H: 4mm) with lengths between 20-180mm. Loads and moments determined from the dynamic simulations were applied at the midpoint. Maximum deflections were calculated for every trial and results were summarized.

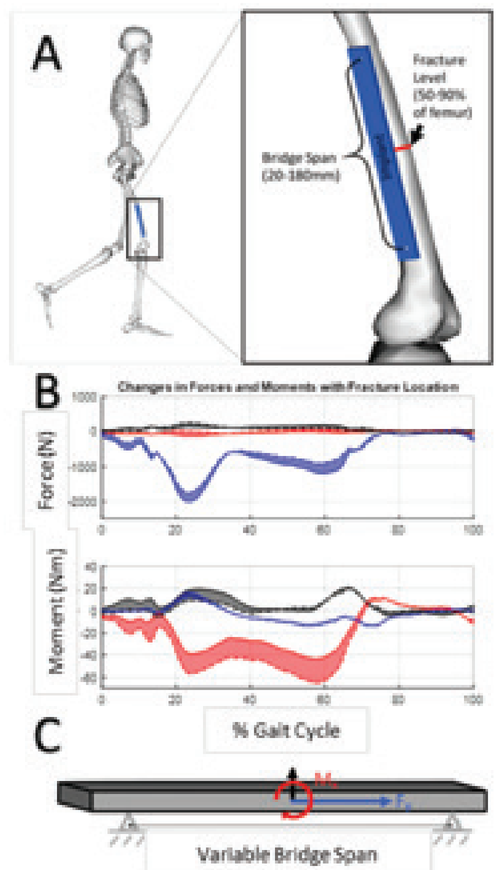

Figure 1. Summary of the methods used in the experiment, involving **(A)** a musculoskeletal model with variable fracture locations; **(B)** variable range of forces and moments applied to the mid-point of the implant; **(C)** application of loads and moments to a uniform beam.

Results and Discussion

The estimated plate deflections were nonlinear and ranged between 0.01–3.57 mm. Plate deflections were slightly lower than an existing finite element model[4] that assessed bridge spans between 20-180mm. Stainless steel simulations had an RMSE of 0.32mm, while titanium simulations had an RMSE of .33mm. Assessments took less than one minute of computational time on a PC with an i7 3.6GHz processor and 16 GB of RAM.

Conclusions

Estimations of deflection were close to finite element solutions, and exceed the "best guess" of a clinician. Future work will validate this model with benchtop testing and will include variations in body mass and activities of daily living. This paradigm could be used quickly and efficiently to guide patient-specific surgical techniques towards an idealized bridge span.

References

1. Ricci WM, Streubel PN, Morshed S, *et al.* Risk factors for failure of locked plate fixation of distal femur fractures: ananalysis of 335 cases. *J Orthop Trauma.* 2014 Feb; 28(2):83-9.

2. Delp SL, Anderson FC, Arnold AS, *et al.* OpenSim: open-source software to create and analyze dynamic simulations of movement. *IEEE Trans Biomed Eng.* 2007 Nov; 54(11):1940-50.

3. Avallone EA, Baumeister T, Sadegh AM. Marks' Standard Handbook for Mechanical Engineers. 11th ed. New York, NY: The McGraw-Hill Companies; 2007.

4. Elkins J, Marsh JL, Lujan T, *et al.* Motion predicts clinical callus formation: construct-specific finite element analysis of supracondylar femoral fractures. *J Bone Joint Surg Am.* 2016 Feb; 98(4):276-84.