Validation of Quasi-Static Gait Model for Biomechanical Testing of Femoral Fracture Fixation Implants

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Disclosures:
M. Wessel: None. J.M. Buckley: None. J. Leasure: None.

Introduction: Few standards exist for in vitro biomechanical testing of orthopaedic implants, and this is especially true for femoral fracture fixation devices. Both overload and fatigue models have been proposed, but loading conditions are not standardized across investigators. A fully validated biomechanical model of the femur during quasi-static single-leg stance (SLS) needs to be proposed to allow researchers to compare and evaluate the performance of current fracture fixation technologies and newer technologies. Roberts et al1 developed a quasi-static SLS model that provides a good starting point for test standard development.1 Their model has been adopted by several other investigators in testing various fracture fixation devices; however, there are some gaps in their model development that need to be addressed.

The goal of this study is to develop and validate a biomechanical testing protocol simulating the SLS of the gait cycle. Our specific aims are: 1) to quantify the multi-axial loads in the mid-shaft femur and compare it to physiological loads; 2) to determine whether distal femoral end-conditions affect the loading state in the mid-shaft; and 3) to determine the appropriate magnitude of abductor muscle forces as well as the most consistent method for applying such forces.

Methods: The basic model for single leg stance (SLS) for this study will be the test configuration from Roberts et al1. In accordance with this setup, the femur will be mounted to a standard test frame (Instron 8521) at 13 degrees valgus to the principal loading direction. The load frame actuator will be connected to a hinge joint that will allow for “pelvic tilt” during axial compressive loading. The femur will be secured to the fixture with various distal attachments and cables used to simulate abductor force in some of the test configurations in this study (Table 1). Our specimen is a composite femur (Fourth Generation Composite Femur, Sawbones) instrumented with a multi-axial in-line load cell (MC3A-500, AMTI) (Figure 1).

Loading conditions for all test configurations were based on the simple static analysis of SLS by Nordin and Frankel that was the foundation for the experimental set-up by Roberts et al.1,2 In this study, BW was taken to be 195 lb for an average size male.3 To ensure non-destructive loading on all of our test configurations, the maximum applied loads were reduced by a factor of 4.31, i.e., ground reaction force of 23% BW and abductor force of 46% BW. The linearity of each testing configuration was investigated by applying loads of 50%, 75%, and 100% of these maximum values. Each load was applied quasi-statically in each testing configuration. A total of 5 trials of 50%, 75%, and 100% loading were applied to each test configuration. Outcome measures for all tests will include mid-shaft multi-axial load state (AP, ML, and axial forces and corresponding moments), measured from the in-line multi-axial load cell and linearity of the test configuration.

Results: None of the models replicated physiological conditions, including the base model from literature (Figure 2).1,4 Setup D (no abductor cable) was not stable enough to be loaded. Configurations with constant force abductor cables (A, B, C) resulted in high variability compared to other configurations. Forces and moments were insignificant between distal end conditions (p>0.9).

Discussion: There are no current biomechanical models that well represent internal physiological loads in the femur. Also, an abductor cable is necessary for model stability and should be applied via constant length cable or cable with in-line spring to achieve repeatability. Distal end conditions were also found to have little effect on internal load in the femur. A different “frictionless” block may provide more accurate results by directly channeling the abductor cable over the greater trochanter. Future work will compare biomechanical model performance in fractured specimens, and may include further development of the model to achieve physiological loads.

Significance: The goal of this study is to develop and validate a biomechanical testing protocol simulating the SLS of the gait cycle.

Acknowledgments: N/A

References: 1. Roberts, et al. (2002) J Orthop Trauma 17(8 Suppl), S57-64
4. Duda, et al. (1997) J Biomechanics 30(9), 933-
Table 3: Test conditions with ‘*’ a baseline condition.

Figure 3: Stress relaxation measurements of each setup. Corresponding literature value in physiology is grey.

Figure 4: Test specimen instrumented with load cell and strain gauge.