Finite element analysis of osteoporotic humerus fractures fixed with locking plate construct

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Objective: Ostoeporitic fracture fixation is a growing orthopedic problem due to the increased incidence and relatively high failure rate of bone fixation. Although the recent advance in locking plate fixation have reduced the incidence of mechnaiocal failure, the proper indication for its use and the diameter of plates and number of screws required for osteoporotic bone fixation is still an unsolved issue. Humerus fractures in the osteoporotic population are still notorious in their high mechanical failure after fracture fixation even with modern implant designs. Also the introduction of newer designs of plate raised the question whether a narrower type of plate (3.5mm locking) could be used instead of a traditional 4.5mm locking plate, and the importance of the plate length to resistance against torsion and bending. The purpose of this study is to create a patient-specific model and mechanically test different plate/screw configurations using a finite-element modeling to serve as a basis for further research in the future.

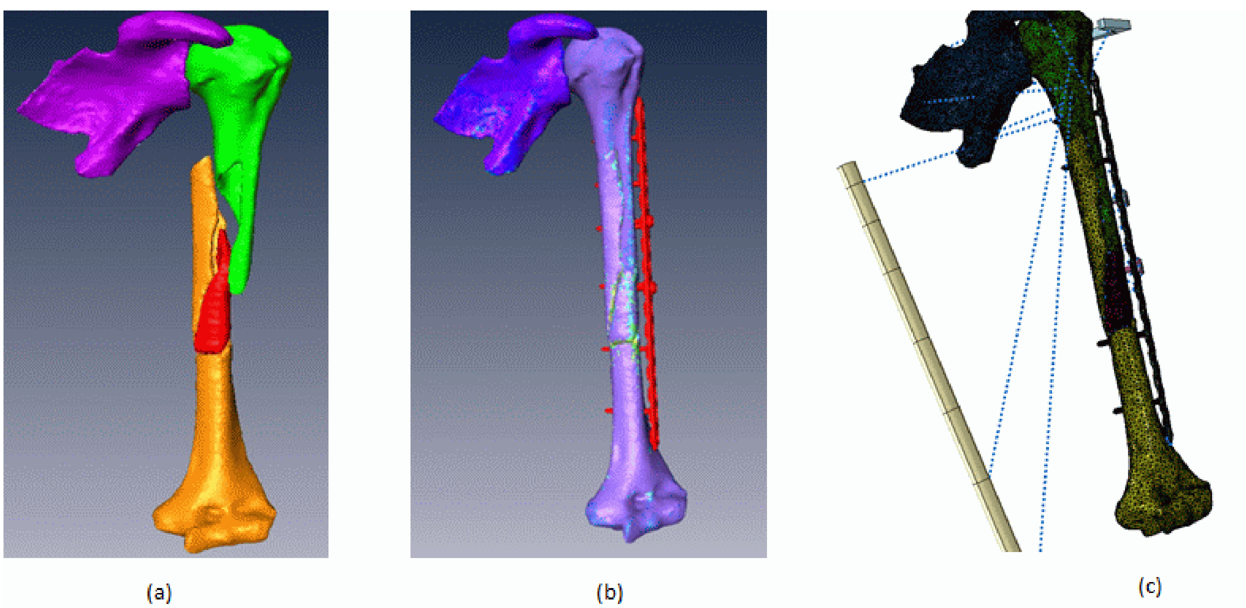

Figure 1 – (a) The bone fragments of the fractured humerus were segmented enabling the creation of a 3D surface model. (b) material properties were applied to all elements of the bone according to a density based empirical relationship. (c) Finite element model of the reduced fracture with a locking plate construct. A long 3.5 plate was fixed to the bone using the technique described in the text. The dotted lines represent muscle line of pull upon the construct. The depicted rod was added to simplify the origin of these muscles. Both locking and compression screws were added.

Model Preparation: An osteoporotic fractured humerus of a 81 year old female was CT scanned (Philips brilliance 64 slice) with a slice spacing of 1mm and pixel spacing of 0.97X.97mm. The data files were imported to AmiraDev 5.3 (Visage Imaging Inc) for preparation of the model prior to the FE analysis. The following steps were performed: 1) the bone fragments were segmented 2) the fracture was reduced applying semi-automatic rigid transformation of all bone fragments 3) implants were positioned 4) volumetric tetrahedral based grids (10-node quadratic elements) were generated using an automatic mesh generator. Material properties were assigned to each element as described by Taddei et al. The density based elasticity relationship applied was 5) boolean cutting was conducted between the implants and bone grids and finally, 6) all the model information (grid topology, material properties and implant positions) was exported to Abaqus 6.9-1 (Dassault Systems Simulia Corp Providence, RI, USA) for FE analysis.

Figure 1 describes the above steps. In all, ten different fixation configurations were prepared in order to analyze different plate length and thickness, number of locked vs compression screws and number of plates. Finite Element modeling Boundary conditions and External forces Muscle forces – the main muscles affecting the proximal humerus were simulated as passive linear springs which react only to tension. The stiffness constant of each muscle represents the normalized forces that are based on the total cross-sectional areas of the shoulder muscles. The clavicle bone and a virtual structure were added in order to enable the insertion of the relevant muscles (figure b). The scapula was treated as a rigid body and boundary conditions were set as zero movement. External forces – two loading conditions were simulated: a pure torque of magnitude 27.5 Nm and a backward force resisting shoulder forward flexion of magnitude 200 N. in both cases the force vectors were applied to elements in the regions of the medial and lateral epicondyles. The magnitudes were chosen to resemble situations in everyday life based on our approximation. The same forces were applied throughout the study to each model, creating a standard mechanical loading conditions for each construct tested. Bone to bone contact – contact condition at fracture surfaces was composed of "hard contact" in the normal direction using a standard penalty algorithm. The stiffness factor was reduced to 0.1 to enable convergence at reasonable computer time. In the tangential direction a coefficient of friction $\mu=1$ was applied to resemble the jagged edges of the bones. The humerus head was attached to the glenoid fossa using 10 linear connector elements. This technique was used in order to create a hard contact condition on one hand and preventing separation of the two bones as if glenohumeral ligaments are present.

Analysis Procedure: Simulating the biomechanical response of a fractured bone fixated with a plate requires following these steps:

1. The compression screws were tightened at a known force of 50 N During the tightening the screw thread was bonded to the bone and hard contact was simulated between the screw head and the plate.

2. Locking screws were bonded to the plate using special connectors. These connectors impose a zero movement condition between the nodes on the screw head to the nodes on the plate resembling a bonded condition.

3. The torque or backward force was applied to distal humerus.

Measurements: For each analysis the following parameters were measured:

1. The number of elements at the regions of the screw threads that exceed a maximal principal strain threshold level of 0.02

2. The maximum stress the develops in the bottom face of the plate

3. The maximal displacement in mm of the distal humerus relative to the proximal humerus Results The results of this study demonstrate clearly that 4.5mm locking or hybrid plates were more resistant to both torque and backward forces than any of the 3.5mm locking plate constructs, and the length of the 4.5mm plate did not change the number of elements passing the critical threshold. Also, double 3.5mm plates were more resistant to torque than a single 3.5mm plate but were still inferior to 4.5mm plates.

Conclusions: This is a preliminary mechanical study demonstrating the clear superiority of 4.5mm locking plate constructs over 3.5 single or double plate in a osteoporotic humerus fracture model. Our patient specific model can serve as a base for creating preoperative mechanical plan that can potentially reduce complications. Further iterations and cadaveric studies are required to further base these conclusions.