

FEA of a proximal humerus fracture with a fixation plate

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Abstract: The fracture of the proximal humerus is the second most common injury to the upper extremity. In severe fractures, surgery may be necessary which can be in the form of a locking plate holding the bones in place. This study examines the effect of including a bonegraft alongside the locking plate. ScanIP and +ScanCAD (Simpleware Ltd) were used to segment the proximal humerus from a CT scan, and to introduce CAD data of the fixation plate and bonegraft. The combined model of image data (proximal humerus) and CAD data (fixation plate, bonegraft) was then meshed in +ScanFE (Simpleware Ltd) where materials and contacts were defined. The materials for the bonegraft and locking plate were linear elastic. The bone material was based on the greyscale values adjusting the material with pixel intensity. Contacts were defined between the bones and from the locking plate to the bones enabling the plate and bones to move or slide. The bonegraft was fixed to the locking plate and bone. In Abaqus/Standard, the distal part of the model was fixed and load was applied on the proximal end of the bone where the body weight was likely to be transmitted. The results showed that the presence of bone graft gave a 60% reduction in pressures at the screw tips, a 150% reduction in pressures along lateral cortex, and was in agreement with the in vitro experimental testing. In conclusion, the locking plate with the bone graft provides a more stable construction.

Keywords: Biomedics, Implantable Medical Device, Humerus, Fracture

1. Introduction

The fracture of the proximal humerus is the second most common injury to the upper extremity. It has been predicted to double over the next thirty years. In 95% of cases the fracture recovery can be managed non-operatively by a simple sling. However for complex fractures such as for osteoporotic patients, the management can be challenging. Therefore surgery is normally required which can either be in the form of primary hemi-arthroplasty or locking plates, Kralinger et al (2004). However functional results from locking plates, as seen in the images below can offer improved functional results, Moonot et al (2007). However there has been a high level of screw cut out in osteoporotic bone, Muckter et al (2001). The older the patient the more likely the humerus will have a substantial loss of bone density causing a complex interaction between the natural bone and plate. One technique to inject bone graft such as a cement in to the humeral head to create a more stable construct. This initial study examines the effect of the presence of a bonegraft alongside the locking plate. Figure 1(a) shows the a X-ray image of the common locations of locking plate failure and Figure 1(b) shows an image during the surgery.

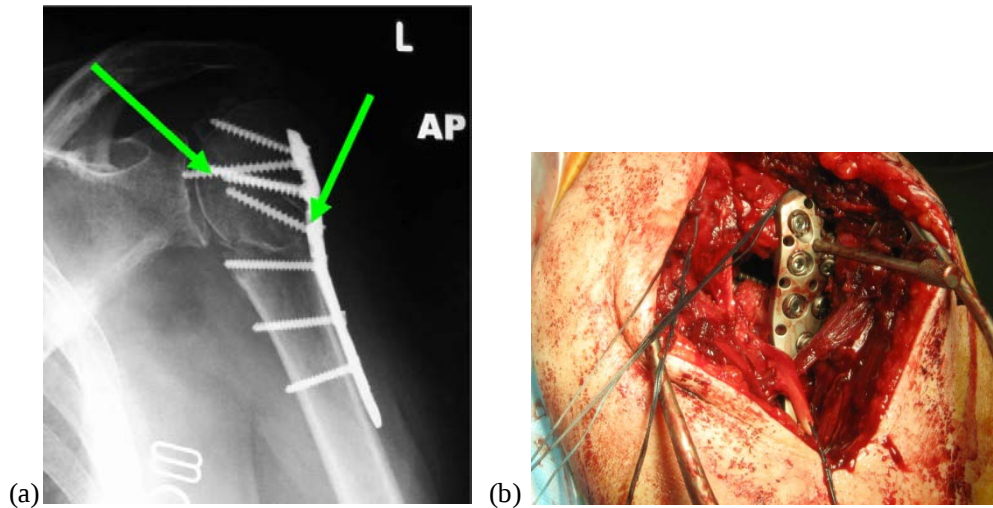


Figure 1. Showing (a) the two common failure locations of a locking plate and (b) an image during the surgery.

2. Methods and model generation

2.1 Finite Element modelling

X-ray Computed Tomography (CT) scan images of a healthy shoulder were obtained and imported into ScanIP (Simpleware, UK) to carrying out the segmentation of the bone. Firstly, the images were filtered to remove noise which then allowed the geometry of the humerus to be segmented in to a mask. The segmentation process used a threshold then a floodfill algorithms to capture the

region of interest. Filters were then used to tidy up the segmentation to ensure any unwanted features were not in the model. For example a morphological close filter was used to fill holes within the mask, then a smoothing filter used to remove artefacts from the surface of the humerus. Figure 2 shows an example of the model creation from the CT data..

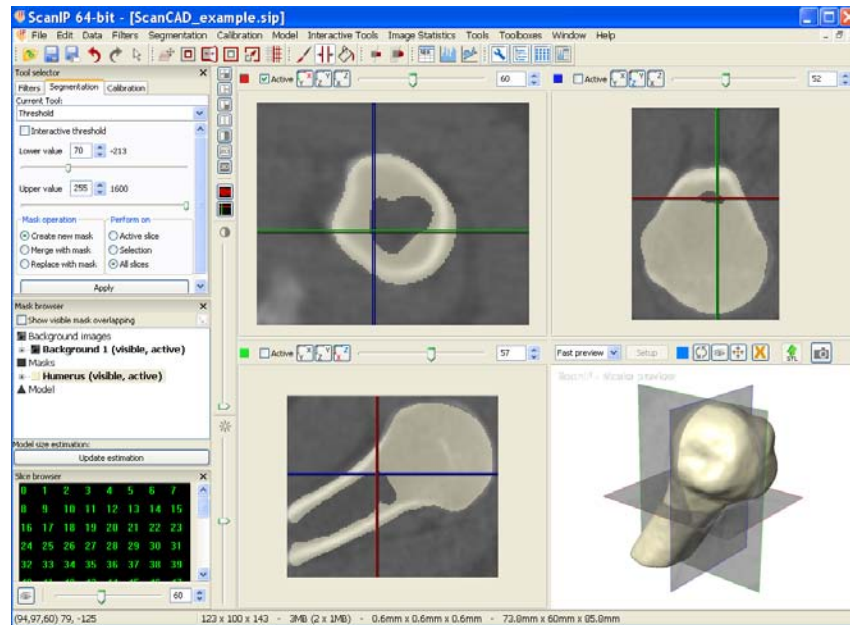


Figure 2 Showing the segmentation and 3D model in ScanIP (Simpleware).

As the CT scan was from a healthy person, no fractures were present. Therefore artificial fractures needed to be introduced. +ScanCAD (Simpleware, UK) allows the integration of computer aided design (CAD) data within the original scan and segmentation. Two cutting planes were imported and positioned to create a 3 part fracture. Boolean operations were then carried out to generate the separations. In addition, CAD models of the locking plate and a ball of bone cement were also introduced. Figure 2 illustrate the process. Young *et al* (2008) describe the mesh generation process in more detail.

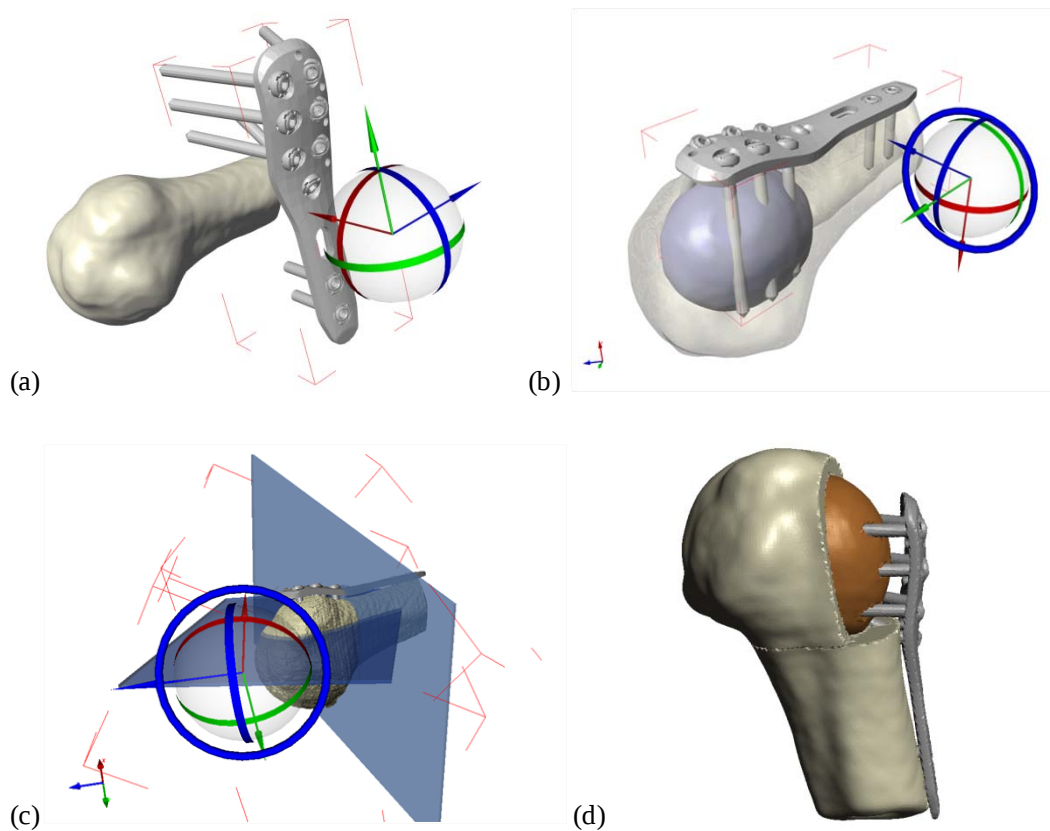


Figure 3. Showing (a) the locking plate before positioning, (b) the cement and plate positioned, (c) the cutting planes to generate the fractures and (d) the final model

The Export option in +ScanFE (Simpleware, UK) enables material properties and contact surfaces to be defined. Whilst material model used for the bonegraft and locking plate was simple homogeneous linear elastic a density-based model was used for the bone. An advanced mapping function that links the greyscale values per pixel into the volume mesh was utilised. Contact surfaces were defined between different parts of the bone as well as between the humerus and locking plate.

The resultant mesh had 1.5 million elements using a mixture of tetrahedral and hexahedral elements. The mapping function from CT scan Hounsfield Units (HU) to density was taken from Rho *et al* (1995). Figure 3 shows images of the mesh. As the interfaces between bone fractures had coincidental nodes and elements, no initial overclosures needed to be specified during the analysis. The interface between the implant and cement remained as a "glued" contact due to the shared nodes.



Figure 4. Showing the final mesh of the humerus, locking plate, cement and fractures

The mesh was imported in to Abaqus CAE as a model in the input file format (*.inp). A single Abaqus/Static loading step was set up. The distal end of the humeral bone was fixed (encastre) and a body weight load was applied at the humeral head. Models were generated with and without the bone cement and the stresses analysed at the key failure locations.

3. Results

The simulations on the two cases (with and without the synthetic bone graft) were compared. Figure 4 shows the stress contours of the humerus fracture without the cement. The locking plate has been removed for clarity. The arrows high light the common failure locations in the model , with the X-ray image for reference. As it can be seen the areas of interest experience high levels of compression. Figure 5 then compares the two models to show the difference between the presence of cement. As it can be seen, the cement alters the stress distribution substantially especially for the superior failure location on the humerus.

From monitoring the peak pressures at the failure locations, it was determined that the presence of synthetic bone graft within the cancellous bone gave a 60% reduction in pressures at the screw tips of the locking plate. In addition, a 150% reduction in pressures along lateral cortex was calculated.

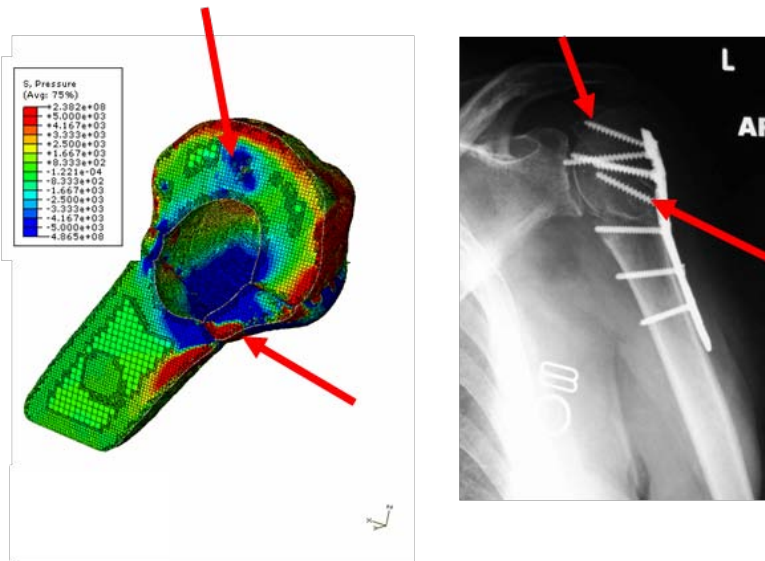


Figure 4. Stress contours cut through view of the humerus without cement (with additional reference to the failure locations)

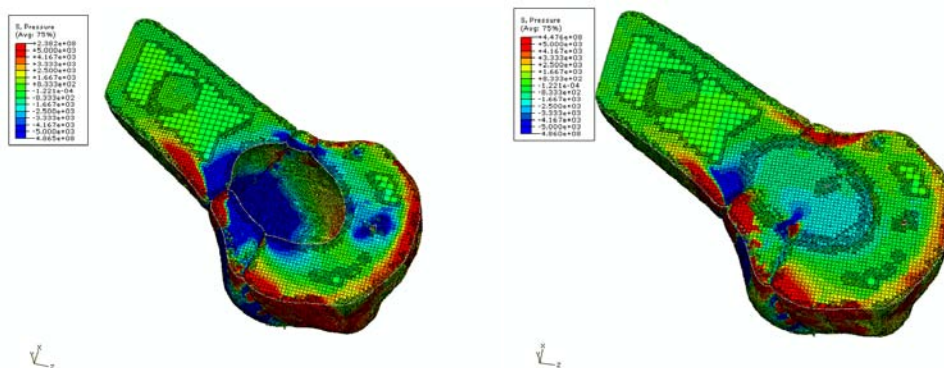


Figure 5. Comparing the humerus with (right) and without (left) the cement (Not to the same contour scale)

4. Conclusion

From this initial study to determine a workflow of mesh generation to simulation for proximal humerus fracture, it was determined that the bone cement offers a more stable construct. The

significant reduction in peak pressures underlines the importance of assessing bone stock prior to fixation. This research will allow further work in this area to investigate the influence of varying the strength of the bone graft. For example a bone cement which is too soft or too stiff could have potentially negative effects on the surrounding or perhaps the locking plate. In addition, a sensitivity analysis of the fixation plate position could straightforwardly be carried out. The automated mesh generation would only then require the boundary conditions to be set. Various locking plate designs could also be easily analysed.

5. References

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