Finite Element Analysis Evaluating Function of LCP System for Osteoporotic Humerus Fracture

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***Abstract*—In this study, we developed a 3 parts fracture model of osteoporotic humerus by reconstructing the four structures of the humerus (cortical bone, trabecular bone, articular cartilage, sub-chondral) using a CT image for 3D CAD modeling. 3D CAD modeling of the fractured humerus and locking compression plate (LCP) system were done with the use of SolidWorks 2017.**

Finite element analysis (FEA) of the osteoporotic humerus 3 parts fracture, LCP system was analyzed by ANSYS Workbench 19.0, and the stress such as Maximum shear stresses on locking screw-cortical bone interface area, Maximum von Mises stresses at LCP and LCP-locking screw assembly was obtained with FEA.

In torsion force applied load condition, the stress occurred in with calcar screw was 50% to 200% lesser than without calcar screw, effect of calcar screws was confirmed.

***Index Terms*—finite element analysis, proximal humerus, osteoporosis, fracture, LCP system**

I. Introduction

Proximal humerus fracture account for about 15% of the population over age 50 and incidence of osteoporosis increases in parallel with the number of elderly people and as a result, proximal humerus fracture rises.

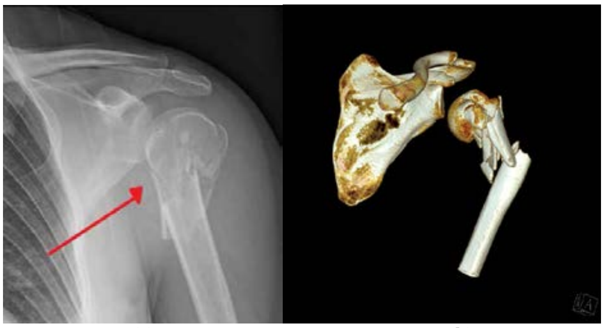
LCP system offers excellent treatment results in proximal humerus fracture fixation [1].

This study deals with FEA to evaluate the function and effect of LCP system and calcar screws. The purpose of this study is to propose surgical treatment criteria using an LCP system in patients with proximal humerus fractures with severe osteoporosis.

II. Material and Method

A. Analysis of the Clinical Radiology Data

Fig. 1 shows the result of high-resolution CT imaging analysis of 50 patients (>60 years old) with osteoporotic fractures. The fractures obtained from the figure were mostly 3 parts comminuted fractures of a surgical neck and greater tubercle. In addition, other studies on LCP and locking screws also chose 3 parts fracture as the main subject as well [2-3]. Thus, the type of osteoporotic fracture model is defined as a 3 parts fracture in this study.



(a) (b)

Figure 1. (a) Anterior-posterior view of a Neer 3 parts fracture through the surgical neck and greater tuberosity. Image of osteoporotic humerus fracture [3], (b) 3 parts fracture CT 3D image on PACS.

B. 3D Model Obtained Form CT Image

Figure 2. High-resolution CT images of humerus on PACS.

We collected high-resolution CT image from the local PACS (Picture archiving and communication system) of Gachon University for 3D model-based FEA. Of these, four image data were selected for 3D modeling reconstruction by analyzing four structures of the humerus (cortical bone, trabecular bone, articular

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cartilage, sub-chondral) and saved as a DICOM format files.

ROI (Region of interest) was drawn on DICOM files and evaluated with Analyze 11.0 program. These were saved as OBJ format files and 3D model was obtained with Meshmixer program.

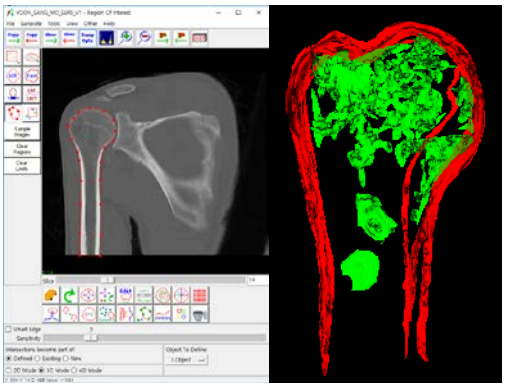

Figure 3. ROI of humerus with Analyze 11.0.

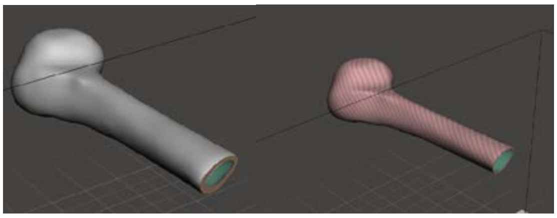

Figure 4. 3D model reconstruction with Meshmixer.

C. 3D CAD Model for FEA

Figure 5. 3D modeling of four reconstructed structures of the humerus (cortical bone, trabecular bone, articular cartilage, sub-chondral) with SolidWorks 2017.

Four structures of the humerus (cortical bone, trabecular bone, articular cartilage, sub-chondral) were edited and assembled for FEA 3D modeling with computer-aided design (CAD) - SolidWorks 2017 (SolidWorks Corp., Dassault Systemes, Concord, MA, USA) and then four humerus 3D modeling were completed from four CT data.

Samples of the LCP system (PHILOS, Synthes, Oberdorf, Switzerland) were supplied and these were characterized by 3 material constants of Young's modulus and Poisson's ratio. 3D CAD models of LCP system were modeled using SolidWorks 2017.

After reviewing the surgical cases of LCP and locking screws [4], one of the most suitable humerus 3D models for LCP attachment was selected as shown in Fig. 6.

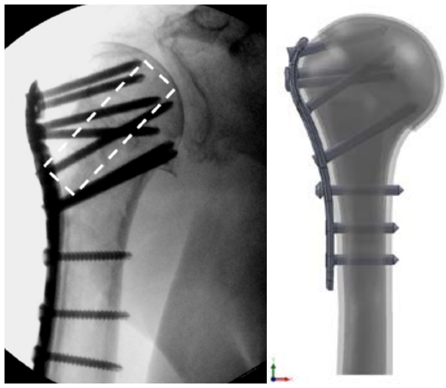

Figure 6. Surgical case of LCP and locking screw and 3D CAD model.

III. Results

A. Finite Element Model

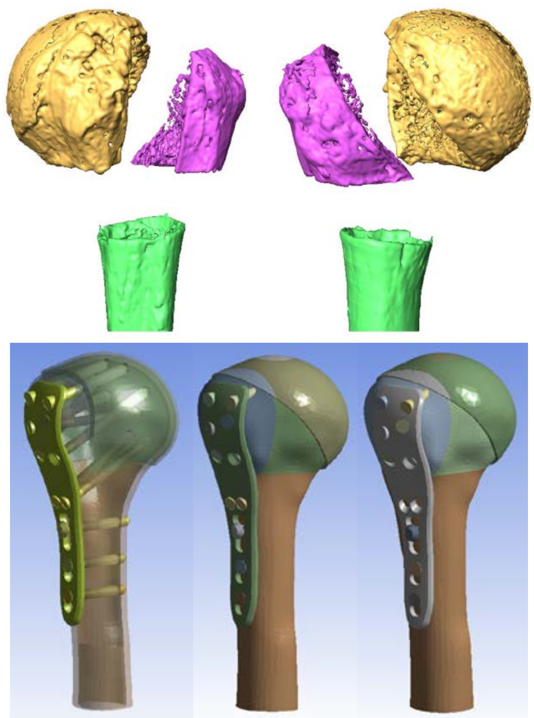

Figure 7. A 3 parts fracture (surgical neck of humerus and greater tubercle) and final two type (model A: with calcar screw, model B: without calcar screw) of 3D CAD model for FEA.

Osteoporotic fracture model was created to reproduce the majority of fracture, which is 3 parts fracture (surgical neck of humerus and greater tubercle) [3, 5]. Also, final two types of 3D CAD model (model A: with calcar screw, model B: without calcar screw) were made and then imported to ANSYS Workbench 19.0 (ANSYS, Inc., Canonsburg, PA, USA) for FEA.

B. *Element Type and Meshing*

A SOLID187 element type that could be used to develop the discretization of the humerus model was used [6]. This element type is composed of 10-node quadratic tetrahedral elements with three degrees of freedom [7].

The current study used humerus=7mm, LCP=3mm, locking screw=1mm as the mesh planning element size respectively and the total nodes and elements were: 655,137 and 362,175 (model A), 641,952 and 354,841 (model B).

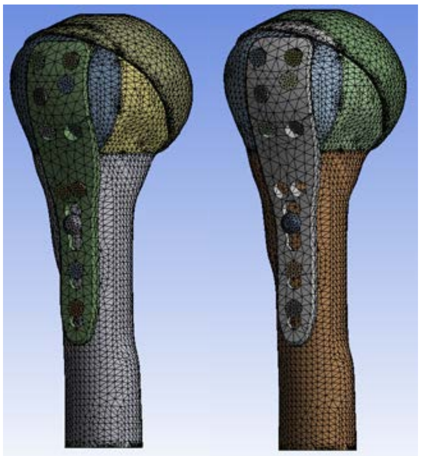

Figure 8. FEA model A and model B after meshing with Solid 187 element.

C. *Material Properties*

FEA model was assumed as isotropic and linear elastic materials. Young's modulus and Poisson's ratio was applied to four structures of osteoporotic humerus (cortical bone: E=12GPa, v=0.3, trabecular bone: E=250MPa, v=0.3, articular cartilage: E=2MPa, v=0.3, sub-chondral: E=3.5GPa, v=0.3) respectively and have been referred to the related references [8].

LCP system was made form titanium alloy (LCP(Titanium): E=110GPa, v=0.3, locking screw(Ti-6Al-7Nb): E=105GPa, v=0.3, cortex screw(TiCP): E= 103GPa, v=0.3).

D. *Boundary Condition*

Contact interactions between humerus shaft, greater tubercle fragment & head of humerus were defined using surface-to-surface finite sliding with a coefficient of friction of 0.3 [9].

Contact condition between four structures of the humerus (cortical bone, trabecular bone, articular cartilage and sub-chondral) was bonded respectively.

LCP system defined as no movement along the interfaces of screw and surrounding bone; screw and plate; screw and cortical bone and trabecular bone and sub-chondral [10].

The distal segment of the humerus shaft was fixed to provide support condition. In addition, shear force, and torsion were applied to the models as a load condition.

For shear force, 500N loads oriented vertically in the coronal and sagittal planes were distributed onto the proximal humeral head and the angle of inclined 20°. The shear force simulated the force that a proximal fracture site would experience while the patient was rising out of a chair or crutch weight-bearing [2]. To simulate rotation, a 200Nmm torque was applied to the proximal humeral head around the axis of the humerus shaft as shown in Fig. 9.

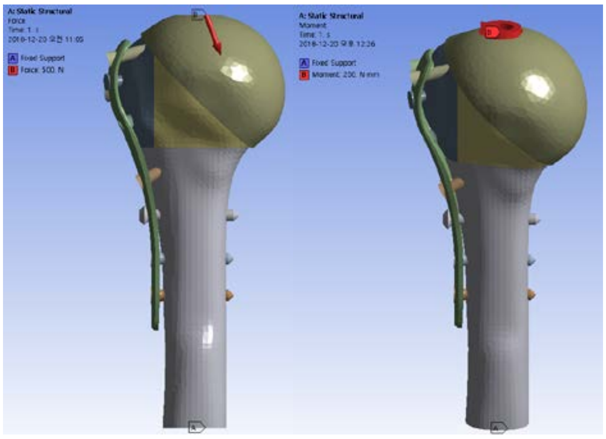

Figure 9. Support and load condition (shear force and torsion).

E. *FEA and Result*

Maximum shear stresses on locking screw-cortical bone interface area, Maximum von Mises stresses at LCP and LCP-locking screw assembly was obtained with FEA.

a. Load condition (shear force=500N / 20°)

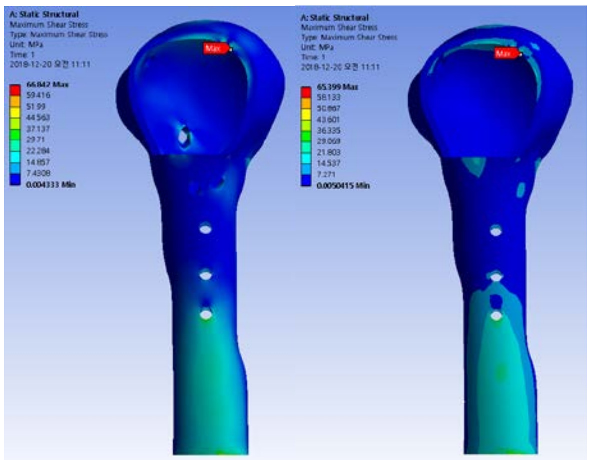

Figure 10. The Maximum shear stresses on locking screw-cortical bone interface at head of humerus.

The Maximum shear stresses on locking screw-cortical bone interface at head of humerus was 66.842MPa (model A) and 65.399MPa (model B) as shown in Fig. 10. Maximum von Mises stresses of LCP at cortex screw holes was 94.401MPa (model A) and 103.04MPa (model

B) were shown in Fig. 11. Maximum von Mises stresses of LCP and locking screw assembly at the lowermost locking screw was 113.59MPa (model A) and 109.35MPa (model B) as shown in Fig. 12.

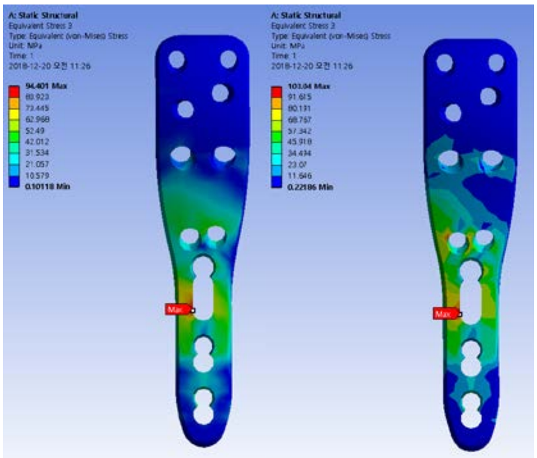

Figure 11. Maximum von Mises stresses of LCP.

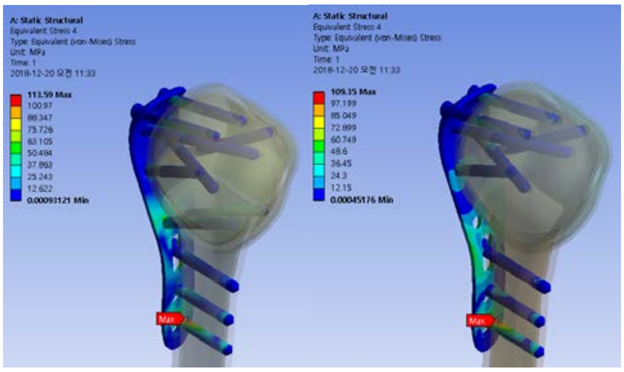

Figure 12. Maximum von Mises stresses of LCP and locking screw assembly.

b. Load condition (torsion=200Nmm)

The Maximum shear stresses on locking screw-cortical bone interface at head of humerus was 2.3912MPa (model A) and at humerus shaft was 5.5864MPa (model B) as shown in Fig. 13. Maximum von Mises stresses of LCP at the back of right calcar screw was 5.0035MPa (model A) and at the back of cortex screw holes was 9.6651MPa (model B) as shown in Fig. 14.

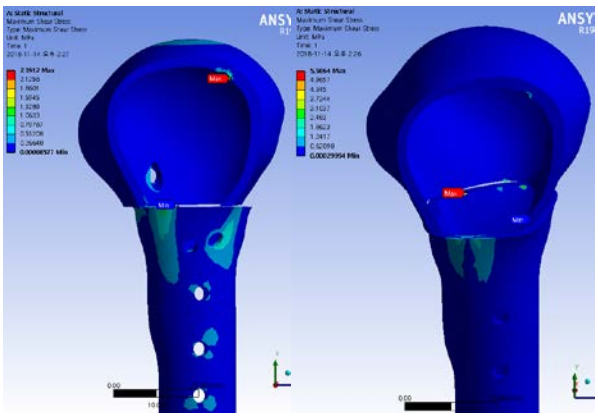

Figure 13. The Maximum shear stresses on locking screw-cortical bone interface at head of humerus (model A) and humerus shaft (model B).

The Maximum von Mises stresses of LCP and locking screw assembly at right calcar screw was 6.0735MPa (model A) and at the back of cortex screw holes was 9.6651MPa (model B) as shown in Fig. 15.

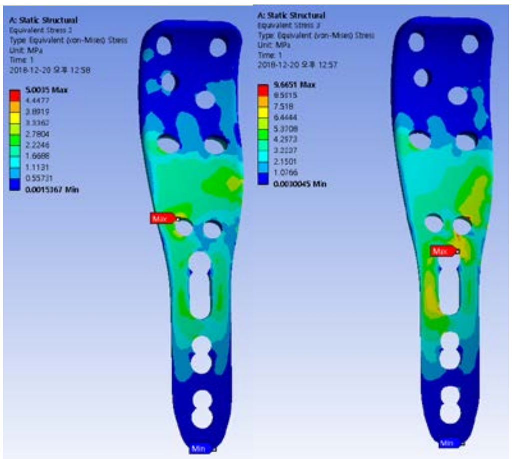

Figure 14. Maximum von Mises stresses of LCP.

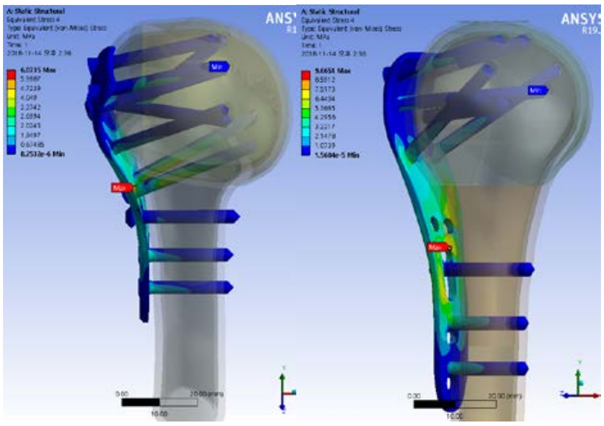

Figure 15. Maximum von Mises stresses of LCP and locking screw assembly.

IV. Discussion & Conclusion

FEA of the osteoporotic humerus 3 parts fracture, LCP system was analyzed by ANSYS Workbench 19.0, and the stress such as Maximum shear stresses on locking screw-cortical bone interface area, Maximum von Mises stresses at LCP and LCP-locking screw assembly was obtained with FEA.

The effect of calcar screws in shear force applied load condition was minimal. Also, the result of stresses applied to FEA model with calcar screw (model A) were similar with the FEA model without calcar screw (model B). The reason for the minimal difference is assumed to be a simple axial force application of which is an angle of 20° inclination. However, in torsion force applied load condition, the stress occurred in model A was 50% to 200% lesser than model B, and the function and effect of calcar screws was confirmed.

We will further work to compare strength with presence or absence of calcar screw under several conditions, analyze and improve the accuracy of the effect of calcar screw with an additional FEA. Also, analyze different factors such as axial or torsion force affecting the results for more realistic condition.

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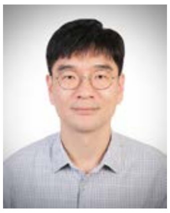

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