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FINITE ELEMENT ANALYSIS ON DUAL SMALL PLATE AND SINGLE FIXATION PLATE FOR DISTAL COLLARBONE FRACTURE TREATMENT

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Abstract

Distal fractures on the collarbone are one of the most common fractures. Using internal fixation is one of the most widely used methods for treating fractures in the collarbone. A dual fixation plate for a collarbone fracture is reported to reduce reoperation due to fixation devices. In this study, the element analysis results will be presented using finite element analysis software (FEA software) for the fixation of collarbone fractures using dual plate fixation, superior plate, and anteroinferior plate. A three-dimensional model of a collarbone fracture with a fracture distance of 3 mm is used to obtain the equivalent von Mises stress value. There was no significant difference in the bending and compressive loadings on the double small plate fixation, superior plate fixation, and anteroinferior plate fixation. The von Mises stress equivalent for double small plate fixation has the most significant value compared to superior and anteroinferior plate fixation. This demonstrates that dual small plate fixation has better biomechanical properties than single plate fixation because it has better stress shielding ability and will accelerate bone healing due to the low load on the collarbone if used by an active patient.

Keywords: Collarbone Fracture, Finite Element Analysis, Biomechanical.

1. INTRODUCTION

Collarbone fractures often occur in athletes due to sports injuries, falls, or traffic accidents. The third distal collarbone accounts for more than 69% of all collarbone fractures. A quick and perfect cure is needed for athletes. As a result, open reduction of collarbone fractures became a widely used option for healing collarbone fractures [1].

Although there are many fixation methods for fractures of the distal collarbone, fixation using plates is still the most well-established method for fractures of the collarbone. Fixation, including anterior, superior, spiral, and, most recently, double plates, is reported to reduce the risk of injury and irritation due to fixation devices [2]. Irritation due to plates usually occurs due to repair operations on the plates [3]. With double fixation plates on collarbone fractures, good postoperative results have been reported, including a 100% bone merging rate and 0% re-surgery [1]. There has been increased attention to the double fixation plate to reduce irritation due to fixation and reoperation.

Previous studies have shown that using double plates in middle-third collarbone fractures has good clinical and functional results. So, the goal of this study is to compare how single-plate fixation and double-plate fixation heal distal collarbone fractures from a biomechanical point of view. Collarbone fractures often occur in athletes due to sports injuries, falls, or traffic accidents. More than 69% of collarbone fractures happen in the third distal collarbone. A quick and perfect cure is needed for athletes. As a result, open reduction in collarbone fractures became a widely used option for healing collarbone fractures [1].

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2. METHOD AND MATERIAL

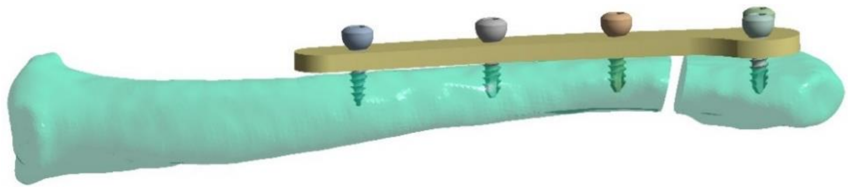

Figure 1. Screw placement on the superior plate

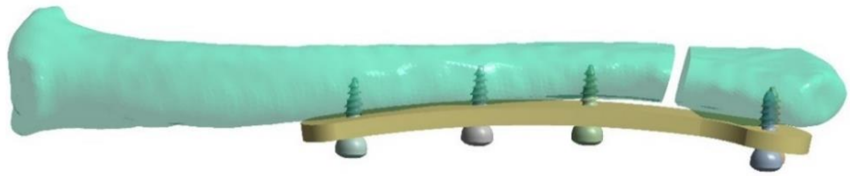

Figure 2. Screw placement on the anteroinferior plate

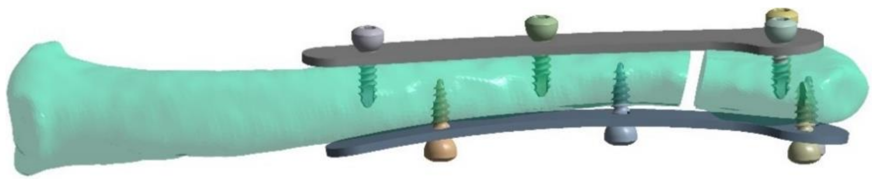

Figure 3. Screw placement on the dual plate

2.1. Model

Table 1. The number of elements and nodes on the bones and plates

Model	Bone	Superior	Anteroinferior	Dual
Nodes	189356	1576	1252	2130
Elements	110211	232	176	608

A model of a bone Computed Tomography (CT) scan on the left collarbone of an 18-year-old male was used in this study. The CT scan results are then processed into a three-dimensional (3D) CAD model using 3D Slicer software. Furthermore, the collarbone CAD model was processed using SOLIDWORKS 2020 to add a cancellous layer to the bone. A fracture gap of 3 mm in the distal collarbone was also added using SOLIDWORKS 2020 software. for 3D models of screws and plates drawn using SOLIDWORKS 2020 using the ISO 5835 standard and manufacturing specifications.

This study used three types of fixation: 1) superior plate fixation with five holes and a plate length of 98 mm, a width of 11 mm, and a plate thickness of 3.3 mm with five 3.5 mm cortex screws. 2). Fixation of anteroinferior plates with five holes and a plate length of 97 mm, a width of 11 mm, and a plate thickness of 3.3 mm with five cortex screws of 3.5 mm 3) Fixation of double plates with four holes as well as superior plate length of 98 mm, anteroinferior plate length of 97 mm, and plate thickness of 1.6 mm, with a total of 4 cortex screws on each plate. On the superior single fixation plate and the anteroinferior single fixation plate, the placement of the screw can be seen in Figures 1 and 2. On fixation, the double plate consists of two plates placed on the superior and anteroinferior collarbones, as seen in Figure 3. After obtaining the assembly model of the entire bone, plate, and screw model, it will be imported into the ANSYS software for meshing on the bone and fixation plate. In this study, the element used was a three-dimensional tetrahedral four-node element to accommodate non-linear geometric analysis. The number of nodes and elements can be seen in Table 1. The mechanical properties of the material used for collarbone and fixation plates can be seen in Table 2. The properties of the material were all taken from the literature [4, 5].

Table 2. Mechanical properties used for the analysis

Material	Young Modulus	Poisson's Ratio
Cortical bone	17900	0,4
Cancellous bone	1000	0,4
SS316L	193000	0,3

2.2. Load and boundary condition

Based on the material properties of the collarbone at the time of abduction movement, this study used two loading modes [6], namely, a bending load and a compressive load of 100 N. The fixed end is placed on the collarbone's sternal back, and both loading modes are located at the acromial end of the collarbone.

2.3. Analysis

This study uses simulations with commercial to-element analysis software (ANSYS Workbench) with outputs or results from Equivalent von Misses Stress (EVMS) on fixation plates and collarbones.

2.4. Model Validation

Validation of bone models is required prior to conducting fixation research. In this study, verification was carried out by comparing perfect bone data or intact conditions with research conducted by Zhang *et al*. and analytically calculated. Both loading modes, namely bending and compressive, show that the equivalent von Mises stress produced has the same tendency and a difference of no more than 10%, which means that the bone model can be verified. Modeling validation can be seen in Figure 4, Figure 5, and Table 3.

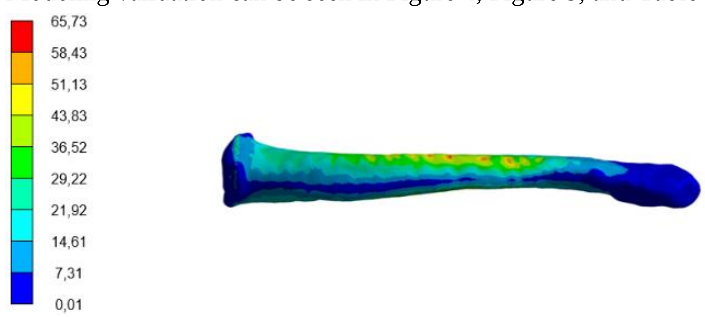

Figure 4. Model validation on the intact bone with bending load

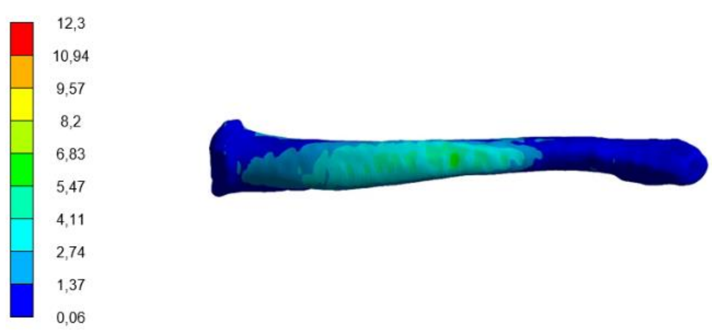

Figure 5. Model validation on the intact bone with a compressive load

Table 3. Model verification result

Load Type	Max. von Mises stress (MPa)	Max. von Mises Stress [9] (MPa)	Stress differences (%)
Bending load	65,73	64,78	1,4%
Compressive load	12,30	11,24	9,0%

3. RESULTS AND DISCUSSION

A fracture of the collarbone is a relatively common fracture, and 30% of collarbone fractures occur in the distal part. Collarbone fractures are common in athletes in professional cycling and the National Football League (NFL). Plate fixation is the most widely used method for healing clavicle fractures, including superior and anteroinferior coatings and, most recently, double small plate fixation to reduce irritation. [8]. This is especially beneficial for surgeons evaluating the biomechanical performance of the implant to improve the healing results of a collarbone fracture.

However, the available biomechanical data is minimal due to the difficulty of direct measurement due to the presence of muscles, ligaments, and the S shape of the collarbone itself. [9]. In this study, FEM was used to predict the causal relationship between the geometric influence of the fixation plate on the collarbone fracture and its analysis. Therefore, this analysis uses a software-based finite element method to estimate three different fixations for distal clavicle fracture healing.

The von Mises equivalent stress distribution in perfect and fractured conditions tends to be higher in bone in fractured states, as seen in Table 4, Figures 6, and 7.

Table 4. Peak von Mises stress on intact bone and plate fixation

Model	Implant stress (MPa)		Bone stress (MPa)	
	Bending load	Compression load	Bending load	Compression load
Intact			65,73	12,04
Superior	350,49	87,69	95,32	13,07
Anteroinferior	316,2	66,04	78,29	13,48
Dual	282,91	25,79	76,43	11,5

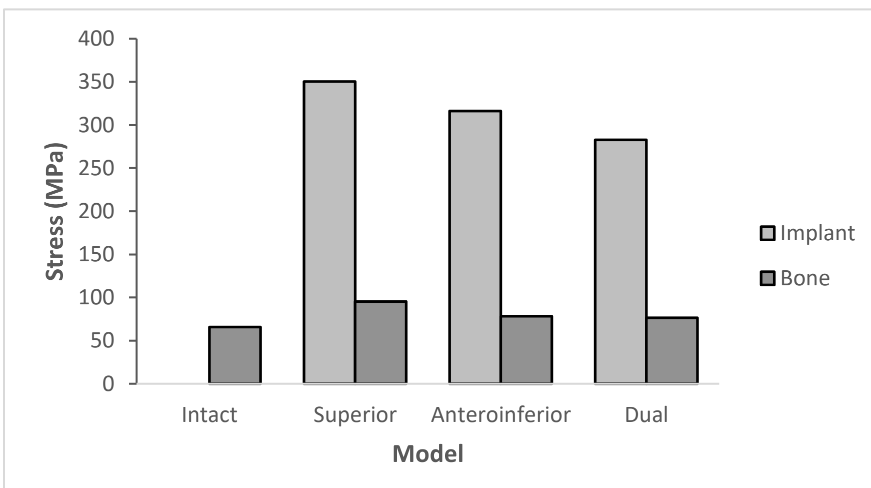

Figure 6. Effect of bending load on stresses

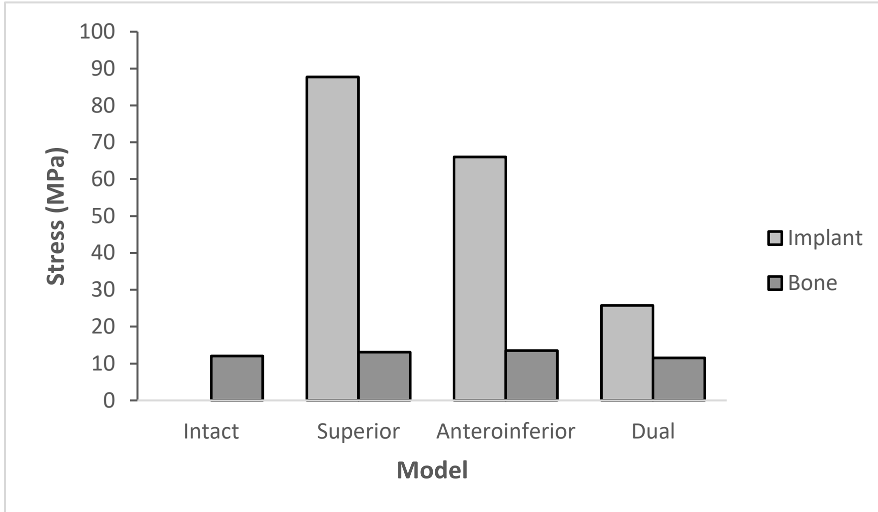

Figure 7. Effect of compressive load on stresses

3.1. Stress Distribution

The von Mises equivalent stress distribution in perfect and fractured conditions tends to be higher in fractured bones. The distribution of von Misses stresses on plates can be seen in Figure 8. Meanwhile, Figure 9 depicts the von Mises stresses from bones. The maximum von Mises stresses on plates and bones against loads are shown in Table 4.

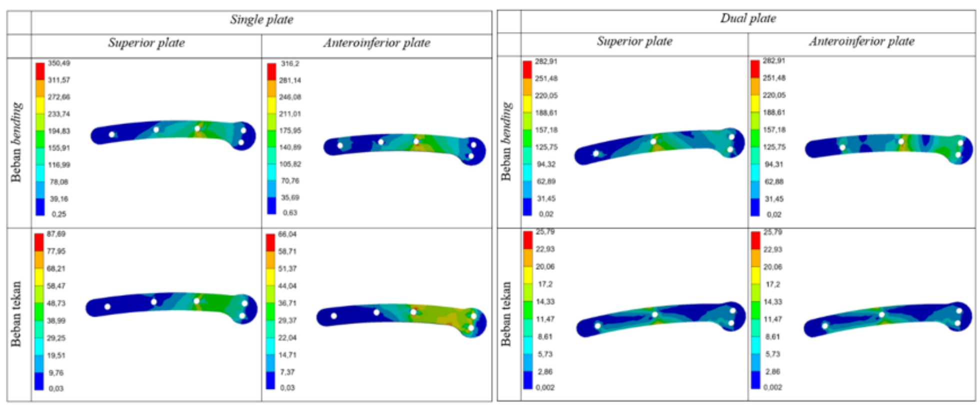

Figure 8. Equivalent von Mises stress distribution on plates

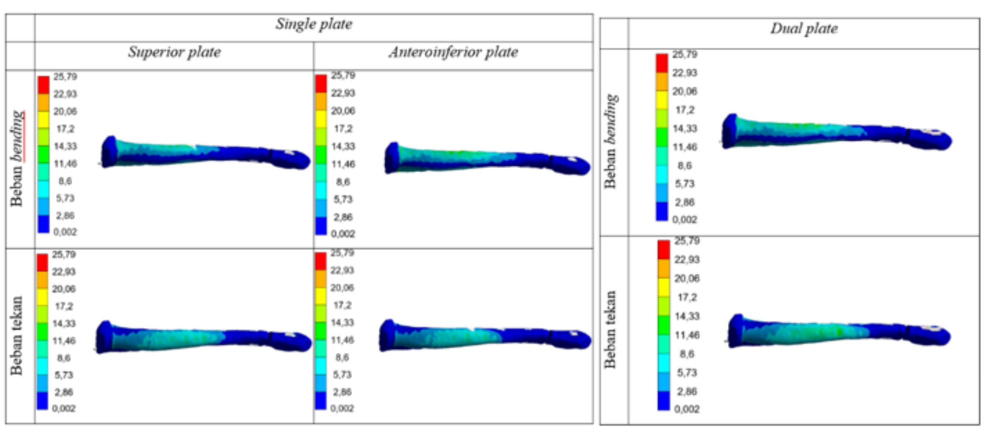

Figure 9. Equivalent von Mises stress distribution on bones

Stress affects bone fracture healing. A fixation that is too rigid will result in less pressure being received by the bone and inhibition of calluses in fractures. In double-plate fixation, the bone's stress is smaller than the superior and anteroinferior plates, which means that the double-plate fixation has a higher shielding stress value than the definitive plate fixation and the anteroinferior plate fixation. As a result, when double plate fixation is used on older adults who do not move much, callus formation is slower than when superior plate fixation and anteroinferior plate fixation are used. Double-plate fixation has a higher and more stable stress shielding ability compared to other fixations, resulting in less stress being received by the bone. The larger cross-sectional area in double-plate fixation results in more stable support than single-plate fixation. Due to the higher fixation stability in double plate fixation, early weight-bearing (EWB) adequacy is better in double plate fixation when compared to superior plate fixation and anteroinferior plate fixation. Weight-bearing is the load the patient can accept on the fractured bone. Patients can withstand loads of shorter duration during bone healing on double plates, which have higher stability, thereby reducing the risk of reoperation due to the failure of fixation devices. This double-plate fixation is suitable for patients who require faster mobility or active patients such as athletes.

4. CONCLUSION

From the results of the stress analysis on superior plate fixation, anteroinferior plate fixation, and double plate fixation, the following conclusions can be drawn:

- Due to loading, bending, and compressive forces, the engineering design of the plate fixation on the collarbone was done with three different ways of putting it.
- The comparison between the intact bone model and the simulation results obtained through the FEM procedure obtained results with error values of 1.4% and 6.8% as the basis for the analysis of double plate fixation and single plate fixation in distal clavicle fractures.
- Double plate fixation has better force distribution than single-plate fixation, so it can provide better stability to the bone.

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