Numerical Analysis of LN 331 S Plate Stress and Deformation in Cranial Fixation

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Abstract: In order to promote the osteosynthesis of a fractured bone, the complete immobilization of the fracture is needed. The surgical plates used have to respond accordingly to forces and deformations which can appear during daily activities or during stress conditions. Nowadays, finite element models are used to design implants, analyze the influence of different factors such as, size, shape, position, elastic modulus, etc. or to study bone variables, such as, geometry, bone density and anisotropy distributions and response to different load conditions. Following this trend, the paper presents a numerical analysis, using Finite Elements Method, of LN 331 S plate stress and deformation when reduces a parietal bone fracture.

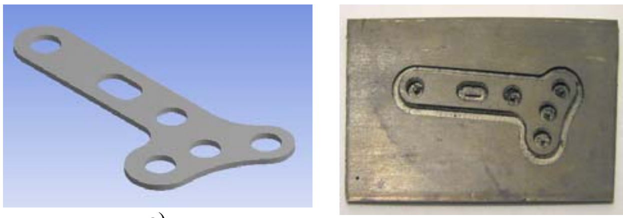
Keywords: fracture reduction, implanted plate, Finite Elements Method, stress and deformation

1 Introduction

Evan during normal daily activities bones must resist to large forces. A special characteristic of bone is its brittleness. When deformed, for example, in elongation, it tolerates a deformation of only 2% before it breaks, resulting the characteristics which are closer to the behavior of glass than of rubber. [5] The fractures treatment aims full and short-time recovery of the skeleton functions and the consolidation of the affected area in order to promote the osteosynthesis. The complete immobilization of the fracture imposes internal fixation directly on the fractured area. The surgical plates used have to respond accordingly to forces and deformations which can appear during daily activities or during stress conditions.

2 Method

One of the most recommended implant fixations destined to repair the skull fractures have the shape of LN 331 S plate in Aesculap catalogue (Figure 1), whose fixation can be realized by using 2, 3, 4 and 5 screws. [3]



a) b)

Figure 1
LN 331 S fixation plate: a) design b) manufactured

This plate can be curved in order to respect the curvature of the cranial vault, but it can fulfill its fixation functions on a plane area too. The surgical plate was manufactured in stainless 316 L steel with 0.8 mm in thickness, by using the *Comp-U-Craft* equipment, which have a milling tool with 30000 rpm and 600 W in power and processed the row material at a milling rate of 122.52 mm/min and an advance rate of 30 mm/min [3].

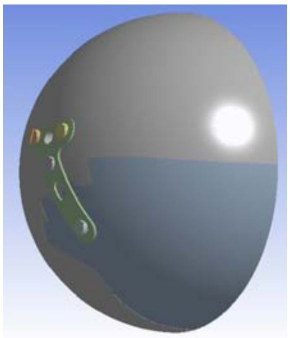


Figure 2
Fracture reduction

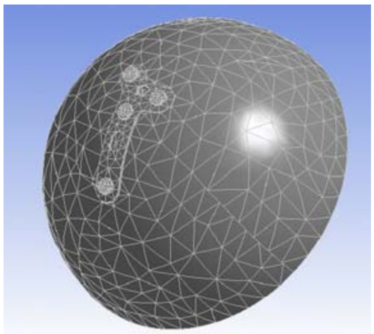


Figure 3
The assembly head bone-plate-screws meshing

The surgical plate is used to fix a parietal bone fracture resulted after an accidental blow. The fracture line is irregular, but it is placed into an area where the external forces are not acting. So, the fixation with a single plate will assure the sufficient compression between the bone fragments in order to promote the osteosynthesis. The plate is fixed by 4 screws in the same material (Figure 2). The assembly *head bone-plate-screws* was modeled by using Finite Elements Method (Figure 3) and the meshing characteristics are presented in Table 1. [4]

Name	**Material**	**Bounding box dimensions [mm]**	**Masse [kg]**	**Nodes**	**Elements**
Parietal bone	Bone	54,68; 59,47; 78,11	0,752	1094	485
Plate	Stainless steel	53,07; 8,73; 26,23	$4{,}15 \times 10^{-3}$	1017	422
Screw 1	Stainless steel	8,44; 7,01; 8,44	$9{,}01 \times 10^{-4}$	1235	669
Screws 2, 3, 4	Stainless steel	6,0; 7,01; 6,0	$9{,}01 \times 10^{-4}$	1235	669

Table 1
Assembly meshing characteristics

In order to study the mechanical behavior of the implanted plate, no exterior forces are considered, the only forces possible being the ones from the fixation screws (Figure 4). The contact area between bone and plate is considered clean, without imbedding between them. This fact allows the distinctive study of the bone and plate mechanical behaviors, the only mechanical links accepted being the fixation screws.

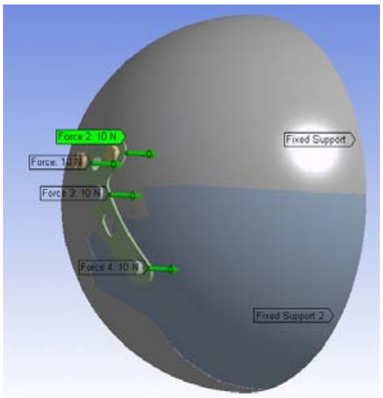


Figure 4
Fixation forces in screws

The values of the grip forces in the fixation screws are depicted in Table 2.

Name	**Tightening force**	**The force projections on coordinate system**
Force 1	10,0 N	[$4{,}44 \times 10^{-15}$ N x, 10,0 N y, $-1{,}13 \times 10^{-15}$ N z]
Force 2	10,0 N	[0,0 N x, 10,0 N y, $1{,}22 \times 10^{-15}$ N z]
Force 3	10,0 N	[0,0 N x, 10,0 N y, $1{,}22 \times 10^{-15}$ N z]
Force 4	10,0 N	[0,0 N x, 10,0 N y, $1{,}22 \times 10^{-15}$ N z]

Table 2
The values of the tightening forces

The physical and mechanical characteristics of the involved materials, important for the FEM analysis conclusions are presented in Table 3.

Characteristics	**Implant material**	**Bone material**
Young modulus	193.000,0 MPa	8.000,0 MPa
Poisson' coefficient	0,31	0,3
Density	$7{,}75 \times 10^{-6}$ kg/mm^3	$3{,}0 \times 10^{-4}$ kg/mm^3
Tensile yield stress	207,0 MPa	100,0 MPa
Tensile ultimate stress	586,0 MPa	135,0 MPa
Compressive yield stress	207,0 MPa	40,0 MPa
Compressive ultimate stress	0,0 MPa	67,0 MPa

Table 3
Physical and mechanical materials characteristic

From Table 3 it can be seen that there are significant differences between physical and mechanical characteristics of the two materials. This is the reason why, in many situations, the manufacturing of implants from plastic materials or composites with properties similar to human bones are preferred. Actually, the fact that the stainless steel used for LN 331 S plate and screws has superior mechanical properties with respect to the bone is not an inconvenient for the mechanical behavior of the assembly head bone-plate-screws, what does really mater being the biocompatibility of the material.

The values of the plate stress and deformations are centralized in Table 4 and visualized in Figure 5 (equivalent stress), Figure 6 (normal stress), Figure 7 (shear stress), Figure 8 (total deformation), Figure 9 (directional deformation X), and Figure 10 (directional deformation Y).

Name	**Minimum value**	**Maximum value**	**Dangerous level**	**Figure**
Equivalent stress	$1{,}11 \times 10^{-4}$ MPa	3,5 MPa	No	Figure 5
Normal stress	-2,4 MPa	1,34 MPa	No	Figure 6
Shear stress	-0,64 MPa	0,64 MPa	No	Figure 7
Total deformation	0,0 mm	$2{,}27 \times 10^{-3}$ mm	No	Figure 8
Directional deformation X	$-3{,}35 \times 10^{-4}$ mm	$4{,}48 \times 10^{-4}$ mm	No	Figure 9
Directional deformation Y	$-9{,}34 \times 10^{-6}$ mm	$2{,}26 \times 10^{-3}$ mm	No	Figure 10

Table 4
Results

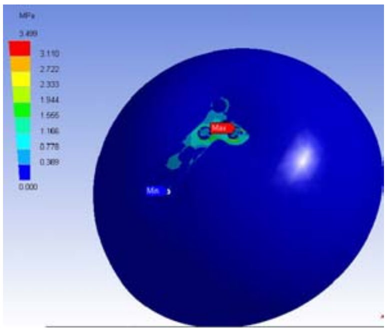


Figure 5
Equivalent stress

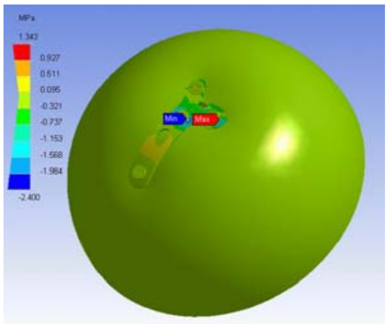


Figure 6
Normal stress

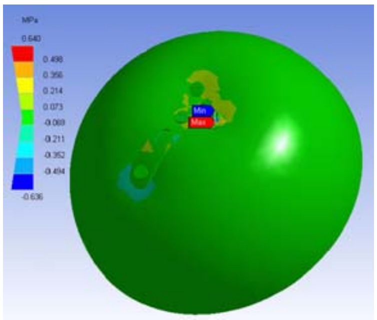


Figure 7
Shear stress

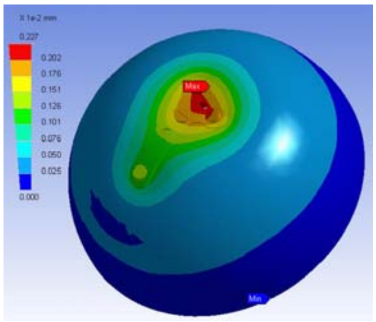


Figure 8
Total deformation

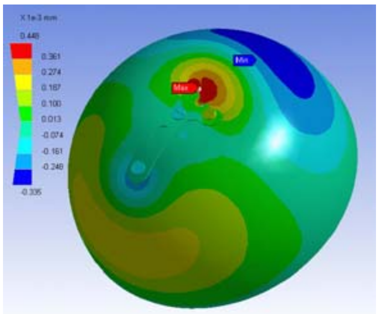


Figure 9
Directional deformation X

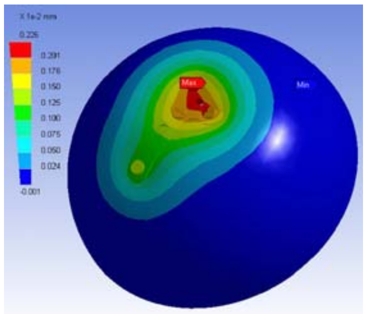
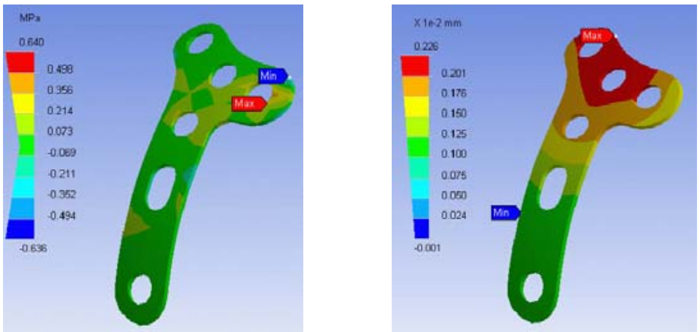


Figure 10
Directional deformation Y

In the case of the parietal bone fracture, the compression force in screws with the value of 10 N along the longitudinal axis of each screw was considered as external load. The stresses in implant plate were well under the accepted limits for the respective material: maximum equivalent stress 3,499 MPa, maximum normal stress 1,343 MPa and maximum shear stress 0,643 MPa. All deformations were very reduced having the size of 10^{-3} – 10^{-4} mm.

In some cases, the most useful representations of stress and deformation are obtained detaching the plate from the mechanical assembly head bone-plate-screws. For example, the shear stress and directional deformation Y are more visible if it isolates the plate, for the same environmental conditions (Figure 11).



a) b)

Figure 11
Isolating the plate: a) shear stress b) directional deformation Y

Conclusions

The study shows that the stresses in implant plate were well under the accepted limits for the stainless steel and that all deformations were much reduced, also. The FEM analysis authorizes the use of the LN 331 L plate to rectify the parietal bone fractures, where external forces are not acting. In this case, the fixation with a single plate will assure the sufficient compression between the bone fragments in order to promote the osteosynthesis.

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