About the Behavior of Fixation Devices on the Fractured Mandible

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Abstract: A lot of studies concerning the mechanical behavior of various surgical implants and bones external supports were developed in the frame of the Multiple Users Research Centre for Modeling Prosthetic Devices and Surgical Interventions on Human Skeleton, functioning in the frame of Politehnica university in Timişoara-Romania, in order to offer to the potential users the optimal corrective solution in the case of accidental or congenital damages of the human skeleton bones. The paper presents the results of the numerical analysis of two different solutions proposed to repair a fractured mandible by joining together the two segments. It was compared a surgical plate fixed by 4 screws with an external fixation device, both of them applied on the same mandible.

Keywords: Bone reconstruction, cranio-facial deficiencies, distractor, modeling, numerical analysis

1 Introduction

There are two methods to fix a fractured bone: *internal fixation* presuming the use of wires and/or plates with screws able to keep together the bone segments; *external fixation* representing the use of surgical pins/screws placed on the bone fragments and connected by some external frame in order to attach the bone fragments in their correct positions [5], [6], [7]. The fixation devices (Figures 1 and 2) were both designed and manufactured in Titanium, material able to assure the needed mechanical properties combined with a small weight and peculiarly, with a perfect biocompatibility.

Figure 1
Surgical plate with 4 screws

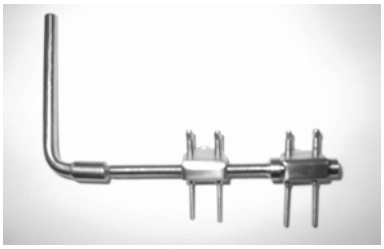


Figure 2
External distractor

These fixation devices have certainly different behavior and besides that, the surgical technique to introduce them in the affected bone zone, is very distinct [2], [4].

Each solution must be analyzed before surgical application in order to establish which of them is appropriated to solve the problem with minimum invasive process and maximum safety. The evaluating methods are medical and engineer. Among the engineer methods, a very important one is the numerical analysis of the assembly fractured bone-fixation devices, able to suggest the appropriate solution from the point of view of stress and deformation distributions.

2 Method

Because the fixation devices must assure the normal functionality of the bone, the assisted broken mandible was studied under the action of mastication forces. By imposing the motion conditions during mastication and by considering the real forces developed by muscles during this motion, the reaction forces acting in the temporo-mandibular joint and on each tooth have been computed [1], [3]. Previous studies showed that the optimal solution to fasten the surgical plate was its fixation by 4 screws (Figure 3). So, the mechanical behavior of the mandible assisted by an external distractor (Figure 4) was compared with this one.

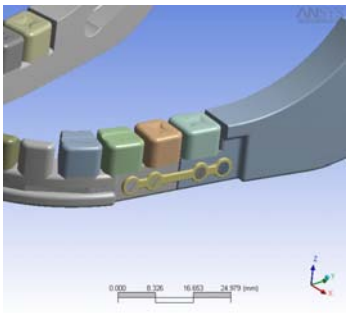


Figure 3
Fractured mandible fixed by surgical plate

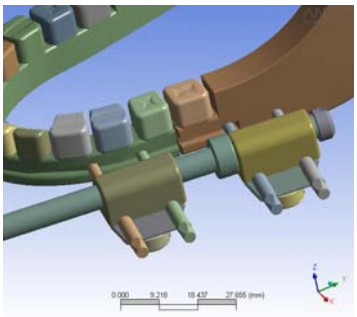
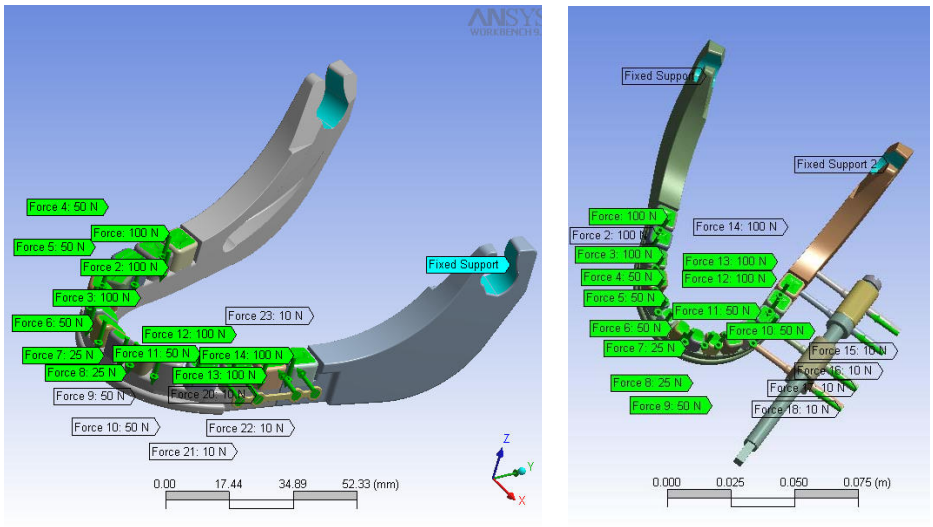


Figure 4
Fractured mandible fixed by external distractor

The study was performed by using ANSYS software. After the model was imported from Solid Edge, the next step was to set teeth/mandible respectively dental implants/mandible contact type. The bounded contact was chosen because it is very closed to the reality. The mesh was realised using tetrahedral elements and the model has 136273 nodes and 81262 elements. The model has a total mass of $7.0*10^{-2}$ kg and a total volume of 44810.65 mm^3. Each tooth was loaded with a force simulating the mastication (Figure 5). Depending on the role of each tooth

during mastication the applied force is variable in the interval [25 N - 100 N]. The load on fixation screws was 10 N in every situation.



a) Fixation by surgical plate

b) Fixation by distractor

Figure 5
The model environment

The toothed mandible was modeled by using the materials properties for bone, teeth and fixation devices as they are presented in Table 1.

Table 1
Materials properties

Material properties	Bone	Tooth	Titanium
Compressive ultimate strength [MPa]	67	360	0
Compressive yield strength [MPa]	40	45	930
Density [kg/mm^{3}]	$6*10^{-7}$	$12*10^{-7}$	$46.2*10^{-7}$
Tensile ultimate strength [MPa]	135	105	1070
Tensile yield strength [MPa]	100	100	930
Poisson's ratio	0.34	0.34	0.36
Young’s modulus [MPa]	8000	10000	96000

3 Results and Discussions

The results of the described analysis were compared with those performed on the healthy non-fractured mandible in order to establish the optimum solution from the point of view of stress and deformation distributions (Table 2).

Table 2
Numerical analysis results

Evaluated elements	**Non-fractured mandible** (type 1)	**Fractured mandible fixed by surgical plate** (type 2)	**Fractured mandible fixed by distractor** (type 3)
Normal Stress [MPa]	150.6500	147.4900	63.0130
Shear Stress [MPa]	39.2400	41.4900	47.0010
Directional Deformation Ox [mm]	0.1300	0.0735	0.0109
Directional Deformation Oy [mm]	1.0500	1.1270	1.0482
Directional Deformation Oz [mm]	0.0693	0.0728	0.0760

The values in table 2 were represented as function of fixation type. It can be seen in figure 6 that, concerning the normal stress values, the optimum solution is offered by the distractor fixation, where the stress value is even lower than in the case of the healthy mandible (approximately 2.5 times lower). Connected with this remark, the deformation on Ox direction is minimum in the case of distractor fixation, but it is 12 times lower than for the healthy mandible (Figure 7).

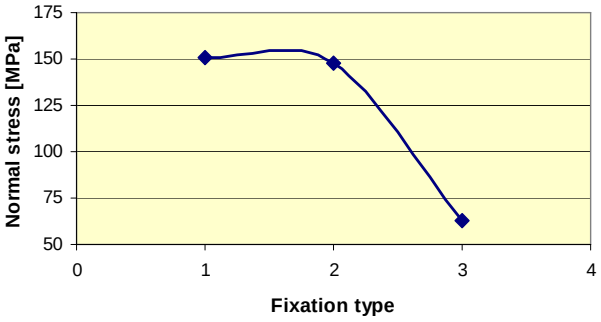


Figure 6
Normal stress

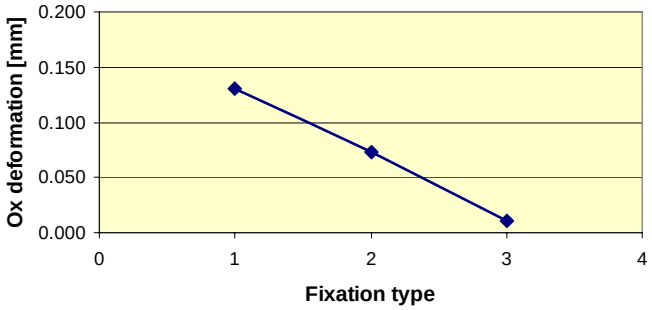


Figure 7
Directional deformation Ox

The shear stress appears as minimum for the healthy mandible (Figure 8), but the stress value in the case of the mandible fixed by surgical plate is very closed with the first one (only 1.057 times greater). Concerning the corresponding deformation on Oz direction, the general tendency is the same, but the increment has a lower slope.

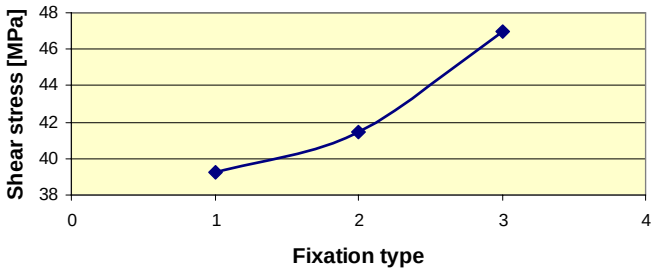


Figure 8
Shear stress

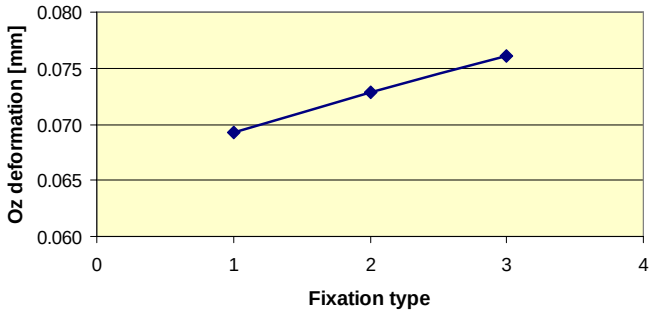


Figure 9
Directional deformation Oz

Conclusion

The results obtained for the fractured mandible fixation with distractor and with surgical implant plate with 4 screws, were compared with the results for normal mandible (no implanted). The principal stresses values correlated with the corresponding deformations recommend the solution of surgical implant much more closed to the healthy mandible behavior. If the medical recommendation imposes a reduced invasive process, than the solution is the external fixation by using the distractor.

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