STRESS/STRAIN FIELD ANALYSIS IN THE MANDIBULOTOMY TECHNIQUE USING THE FINITE ELEMENT METHOD

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Abstract. *The index of tumors in the oral cavity significantly increased, mainly, due to the use of tobacco. In the majority of the cases, the treatment form of these tumors is its resection. This process is made through the access to the oral cavity using the mandibulotomy technique. Thus, types of cut in the mandible in function of the tumor position and the condition of the patient can have different forms. The fixation cuts, in general, is made through miniplates and titanium screws or steel wires. This work was proposed to evaluate one type of cut in a mandible, midline mandibulotomy, using different sets of fixation. The finite element model simplified is used to evaluate the stress distribution. It is intended to evaluate the models qualitatively with applied load, aiming at to evaluate if problems with osteosynthesis will be able or not to occur. These analyses had allowed the surgeon to evaluate, under the biomechanic point of view, the adopted surgical procedures.*

Keywords*: Mandibulotomy, Miniplates and Titanium Screws, Stress Analysis, Finite Element Method.*

1. Introduction

Head neck cancer is not a modern disease. Defects in the skull base indicative of nasopharyngeal carcinoma have been described in Egyptian skulls dating from 3000 BC, and a range of jaw and skull tumors was found in prehistoric Peruvians (McGurk and Goodger, 2000).

A number of factors have been incriminated in the induction of oral cancer. The main risk factors are: male above 40 years, excess in consumption of tobacco and alcohol, poor oral health and hygiene, prosthesis badly adjusted, malnutrition, immunodepression, viruses, familial aggregation and genetic susceptibility (Brasil. Ministério da Saúde, 2002).

Mandibulotomy (Fig.1) or mandibular osteotomy has become a commonly used approach for the resection of tumors in the oral cavity, oropharynx and parapharyngeal space (Spiro et al, 1985; Dubner and Spiro, 1991; Amin et al, 1999) that, otherwise would not be accessible through the open mouth or for the inferior access of remnant of the face. Roux first described this approach in 1836 (McGurk and Goodger, 2000).

In cases where the tumor does not closely approximate or directly invade the mandible, mandibulotomy allows maintenance of mandibular form and function while allowing increased access (Shah and Kowalski, 2000).

Mandibulotomy can be performed via anterior to mental foramen, median mandibulotomy, or posterior to mental foramen, lateral mandibulotomy. Lateral mandibulotomy is nowadays seldom used because of its high complication rate, especially in patients undergoing radiation terapy. Median mandibulotomy can be further classified into midline mandibulotomy, which goes between the 2 central incisors, and paramidline mandibulotomy, which goes between the lateral incisor and canine tooth (Dai et al, 2003; Pan et al, 2003).

In a classical midline mandibulotomy the genioglossus, geniohyoid and mylohyoid muscles have to be transected. However, in a paramidline mandibulotomy the genioglossus and geniohyoid can be preserved. Transection of the genioglossus and geniohyoid muscles in midline mandibulotomy may lead to delay in the return of the swallowing function. On the other hand, by performing the paramidline mandibulotomy between the lateral incisor and the canine, the surgeon is taking the risk of harming the canine, which is the strongest tooth that might be more necessary to preserve than a medial incisor (Pan et al, 2003).

The location of the mandibulotomy in midline offers some distinct advantages. First, it allows the least disruption of blood supply and the use of straight-line osteotomy is also important in minimizing bone loss along the healing site (Amin et al, 1999).

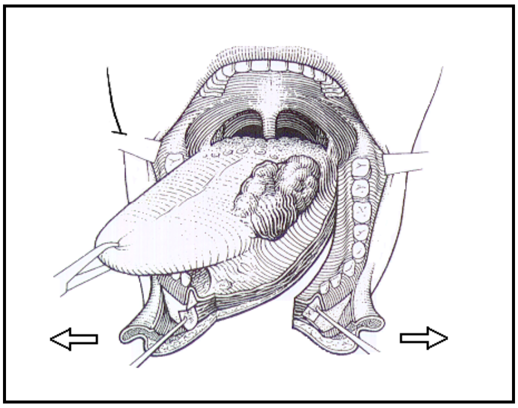
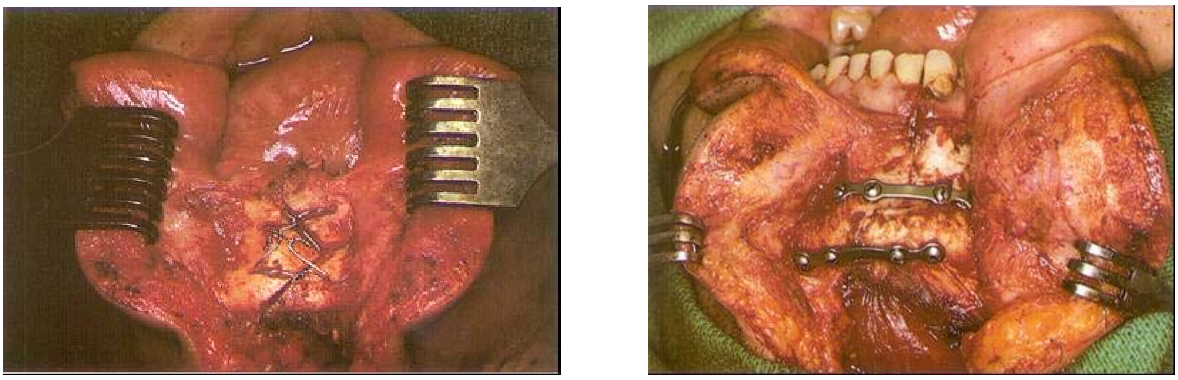


Figure 1. Mandibulotomy - approach of tumor

After tumor extirpation, it is necessary to reapproximate the parts of the mandible. There are two types of fixation: steel wire and miniplates of titanium (Fig.2). Wire fixation has largely been replaced with miniplate (Shah and Kowalski, 2000).



(a) (b)

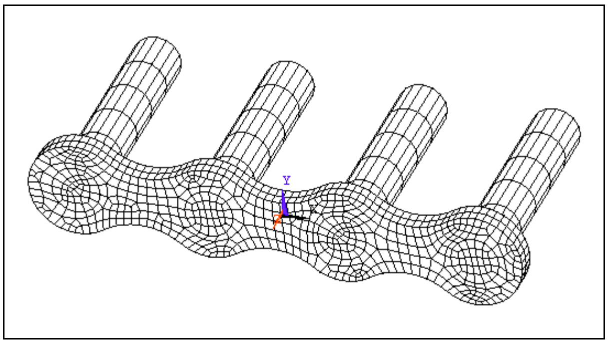
Figure 2. Types of fixation: (a) Steel wire, (b) Miniplates and screws of titanium

2. Materials and methods

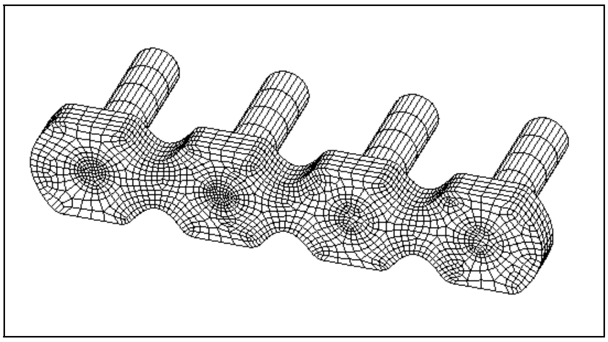
In this work, the main objective is to verify what happens around the site of mandibulotomy, the surfaces in contact and compare with severals sets of fixation with miniplates. Until now, there is no data or study that shows the ideal type and configuration of miniplate(s) to provide fixation of mandibulotomy. It is known that the best fixation is one that keeps the surfaces together, without displacement, and does not generate high levels of stress. If the site of the mandibulotomy undergoes high displacements and stress, the osteosynthesis will be harmed and will occur non-union or malunion. The rigid fixation techniques provide a stable means of immobilizing the osteotomy without the requirement for postoperative intermaxillary fixation (McCann et al, 1994).

The mechanical behaviour of the mandible is far from being fully understood. So, a simplified model was made approaching the mental region of the mandible as two blocks (cancellous bone was rejected and the main dimensions based in a real mandible) that will be fixed with miniplates and pins, simulating the union of the parts with midline mandibulotomy. The models and their configurations of fixation had been analysed using the finite element modeling (FEM) with Ansys. FEM has been widely used to evaluate the stress in biological components and biomechanical events.

One or two miniplates across the mandibulotomy are used to reapproximate and secure the mandible by surgeons. Two types of miniplates were used in this work (Fig.3). We approach screws as pins because contact elements in threads are hard due to their complex surface, causing problems in these specific models. Thus, a friction coefficient of 0.5 was adopted, simulating osteointegration between screw and bone. The same number of coefficient was used in the osteotomy area. Miniplates and pins were glued as if it is one piece of the same material titanium. The thickness of the miniplates are 1mm (Fig.3a) and 2mm (Fig.3b) and the hole diameters are 2.2mm (Fig.3a) and 2.8mm (Fig.3b).



(a)



(b)

Figure 3. Finite element models of miniplate and pins

The properties of titanium (Menicucci et al, 2002) and cortical bone (Korioth et al, 1992) had been used in the FEM (Tab.1 and Tab.2).

Table 1. Isotropic material properties

Material	E (MPa)	ν
Titanium	103400	0.35

Table 2. Orthotropic material properties

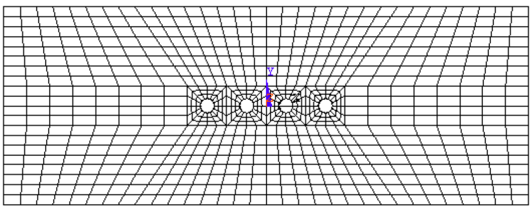
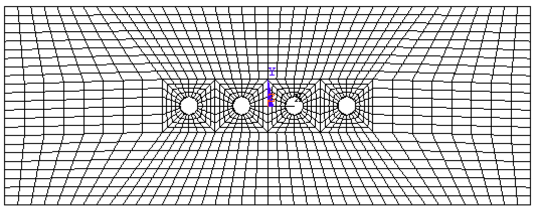
Material	E (MPa)			ν			G (MPa)		
Cortical bone	X	Y	Z	XY	YZ	XZ	XY	YZ	XZ
Mental region	23000	15000	10000	0.3	0.3	0.3	6200	3600	4800

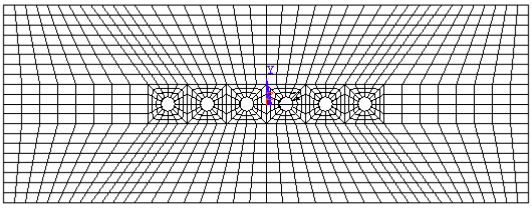
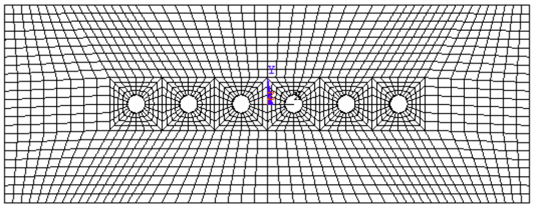
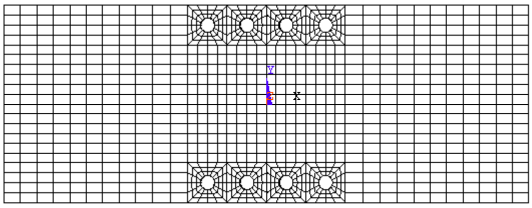
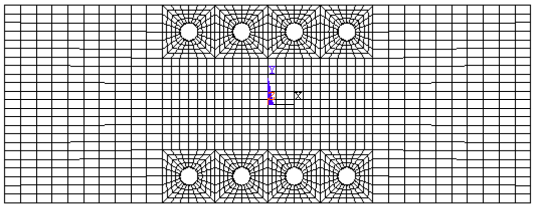
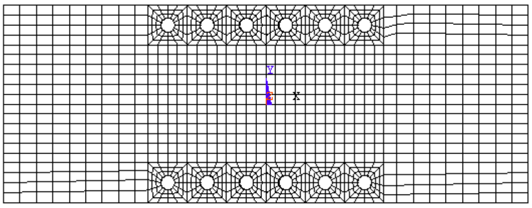
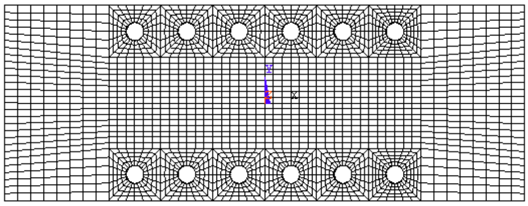
The element types chosen in Ansys are:

1. Plane185: is used for 3D modeling of solid structures. It is defined by eight nodes having three degrees of freedom at each node with translations in x,y and z directions.
2. Targe170: is used to represent various 3-D “target” surfaces for the associated contact elements (Conta174, in this specific case). The contact elements themselves overlay the solid elements describing the boundary of a deformable body and are potentially in contact with the target surface, defined by Targe170. This target surface is discretized by a set of target segment elements and is paired with its associated contact surface via a shared real constant set.
3. Conta174: is used to represent contact and sliding between 3-D “target” surfaces (Targe170) and a deformable surface, defined by this element. The element is applicable to 3-D structural contact analysis. The surfaces of contact are between the pins and bone, and the surfaces in the region of osteotomy. Contact problems can be analysed as a particular case, such as, for example: in big structures with small regions in contact, this region can be analysed separately. It is not necessary in solving all the problems. Another study could be done varying the friction cofficient, although it is not our concern for a while.

Eight models were made in the following configurations of fixation as given in the Table 3.

Table 3. Groups of the finite element models

Models	Miniplate – 1mm - Fig.3a – (A)	Miniplate - 2mm - Fig.3b – (B)
1° *1 miniplate (4 holes)*	 6646 elements (7943 nodes)	 5800 elements (7752 nodes)

2° *1 miniplate (6 holes)*	 8910 elements (10974 nodes)	 7459 elements (10031 nodes)
3° *2 miniplates (4 holes)*	 9359 elements (11505 nodes)	 7780 elements (10332 nodes)
4° *2 miniplates (6 holes)*	 12738 elements (15648 nodes)	 11120 elements (14796 nodes)

The boundary condition had been made in the following way: the main condition occurs when there is an occlusion in the central incisors. Figure 4 shows the mental region with one 1mm-miniplate placed in the mandibulotomy site. Thus, a pressure of 0.1 MPa was applied along the upper surface (40N distributed of each segment) and the nodes of the corner line were restricted as shown in Figure 5.

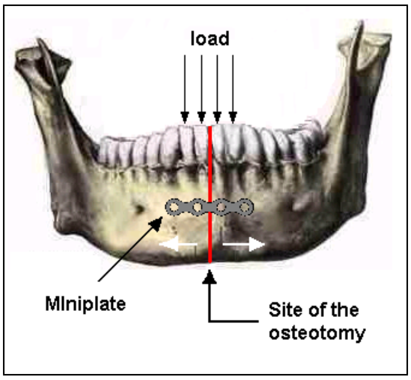


Figure 4. Occlusion in the central incisors with mandibular osteotomy

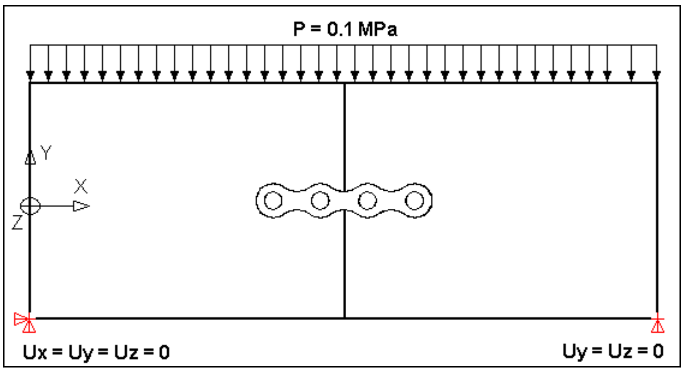
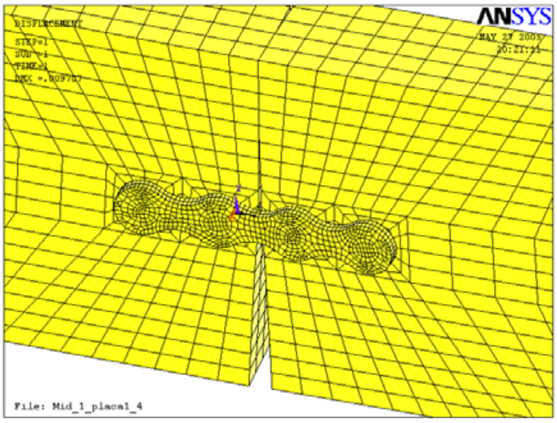


Figure 5. Boundary conditions

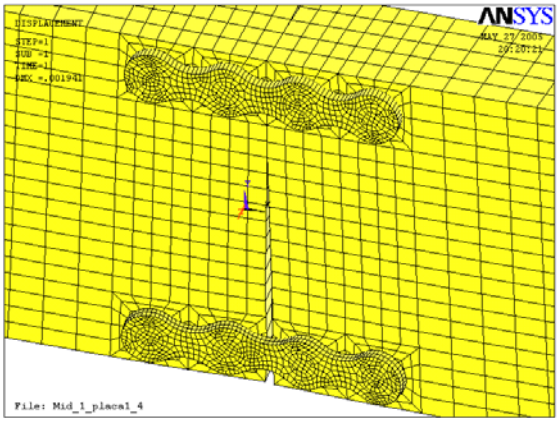
According to many surgeons, this condition is a hard situation for the osteosynthesis.

3. Results

Figure 6a shows a view of the first 1mm-plate model in its deformed state. The opening which is visible in the mental region causes concern to many surgeons, because it damages the osteosynthesis. In opposite, Figure 6b shows the third model 1mm-miniplate where the opening does not occur.



(a)



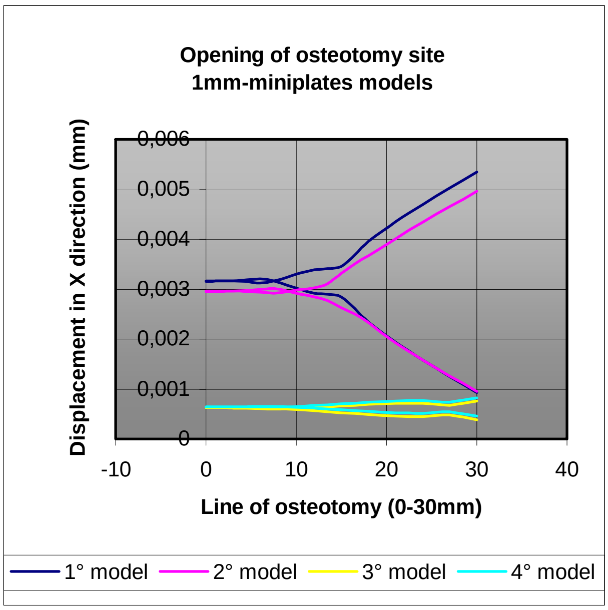
(b)

Figure 6. Deformed state: (a) First model 1mm-miniplate; (b) Third model 1mm-miniplate

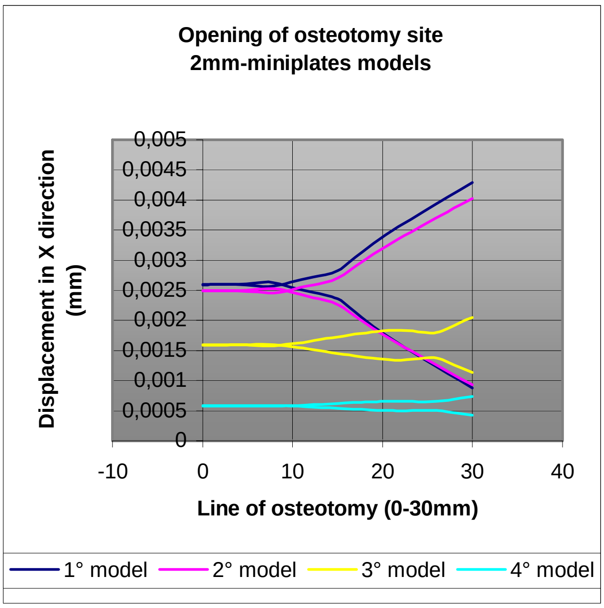
Figure 7 shows the displacement in x direction between the osteotomy surfaces of the first group (configurations with 1mm- miniplate) and the second one (with 2mm-miniplate), that it is the opening along the line of mandibulotomy site. The y and z directions were rejected.

The distribution of stress along the line of osteotomy is shown in Figure 8. The data was disposed jointly for comparison inside each group.

Figure 9 shows the Von Mises stress of the fourth model with 1mm-miniplate.

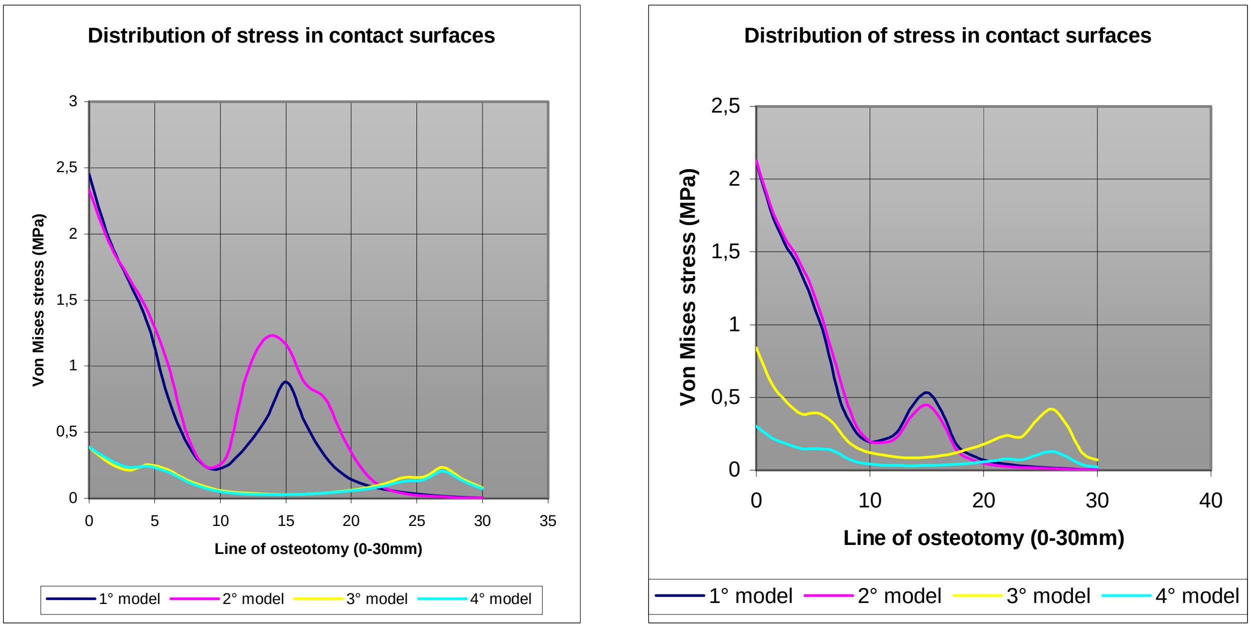


(a)



(b)

Figure 7. Displacement of osteotomy surfaces: (a) 1mm-miniplate; (b) 2mm-miniplate.



(a) (b)

Figure 8. Distribution of stress in contact surfaces: (a) 1mm-miniplate; (b) 2mm-miniplate.

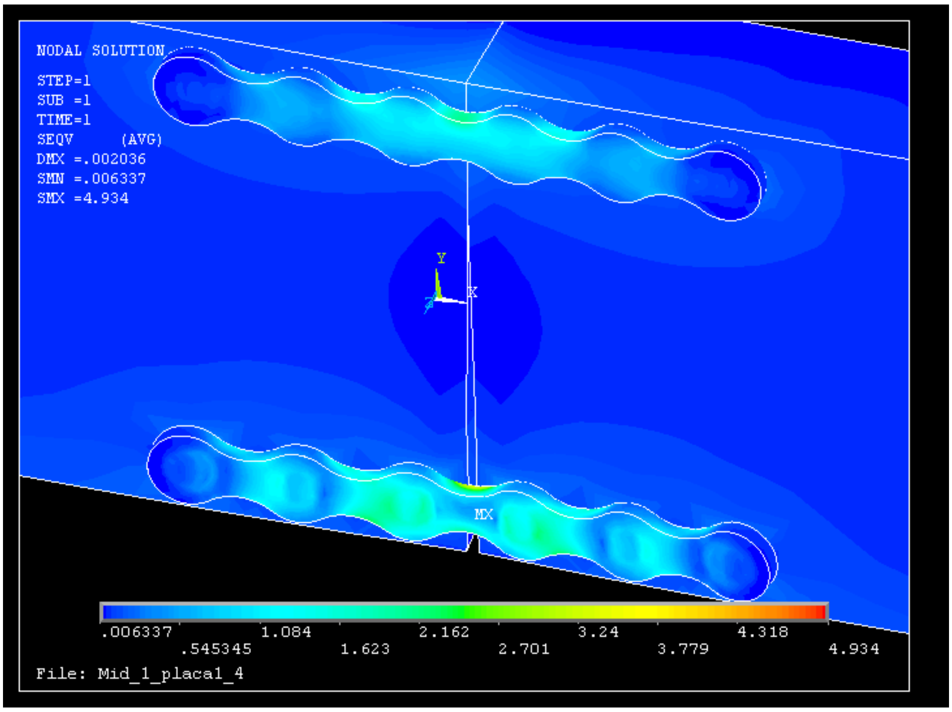


Figure 9. Von Mises stress in forth model 1mm-miniplate

4. Discussion

The complications associated with the use of rigid fixation techniques in mandibulotomy are close to the position of each miniplate. This study shows only two types of plates and four configurations of the plates. There are many types of miniplates, depending on specific conditions of the patient. There is a large range of problems such as malpositioned segments, inadequate fixation and trauma in adjacent structures, etc.

Until now, there is no data about the ideal type of configuration. After this first study we intend to start modeling a human mandible with its curvature. In this way it will be possible to achieve a model of paramidline mandibulotmy and compare two types of mandibulotomy.

The results show that the opening increase in the under mental region when one miniplate is placed. Figure 7 shows the opening in both miniplates that are almost the same in all of them. Thereby, it does not matter if the miniplate has 4 or 6 holes. In the first group (Fig.7a) the best configuration is third model, even though the fourth one shows similar behaviour. The second group presents the fourth model as the best configuration and the remaining models appear with small differences if compared to the first one. Thus, we can affirm that arrangements will warrant a faster osteosynthesis and wound healing. Whereas these configurations are considered here as the best, the surgeons can not place them in dentulous patients, because it is possible to harm the incisors roots.

Beyond the displacements, high levels of stress are not desirable. It is a cause of the phenomenon of reabsorption, harming the bone. Furthermore, comparing the distribution of stress between the models (Fig.8), the two-miniplates arrangement provide a better distribution. The single placed 2mm-miniplate achieve less stress than the 1mm-miniplate. Instead, when two miniplates are placed, the difference disappears. The third model in the second group presents stress higher than the first one. It is noteworthy that the behaviour of the models were close to each other when compared to groups of 1mm-miniplate and 2mm-miniplate.

Figure 9 shows the structural importance of using two miniplates configurations. The miniplate situated below the mental region is more requested than the prior. In the majority of cases, the critical load occurs as shown in Figure 4, so this kind of modeling is reasonable. Diameters of the holes influence the distribution of stress, causing a concentration of stress and a reabsorption.

All models generated small displacements. Therefore, the main consequence of rigid fixation was achieved. Even these displacements can damage the union of bones. Static load was applied instead of dinamic load and the mandible does not have a routine of static bites.

5. Conclusions

This work demonstrated the significance of a rigid fixation, as a structural problem, after mandibulotomy. Unfortunately, most papers do not report it. The concern of surgeons is avoiding delay of wound healing in patients. In this way, it must maintain the osteotomy site immobile for the osteosynthesis.

Finite element modeling is a mathematical model of the real object and/or phenomenon. Consequently, it is usually impossible to reproduce all details of natural behaviour. On the other hand, a Finite Element Model has enormous advantages over *in vivo* testing, precisely because the mathematical model is virtual and controllable. For example, a researcher can easily change the test conditions, the model parameters and the geometry, and can simulate any desirable response and can repeat the simulation at any time.

The simplified model of a complex problem was achieved and can be used to get information about many other miniplates, comparing which one is the best as a structure and using another type of load.

The next step is modelling a real human mandible that is possible to simulate the paramidline mandibulotomy, considering its curvature.

6. Acknowledgments

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7. References

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