15º POSMEC - Simpósio do Programa de Pós-Graduação em Engenharia Mecânica
Universidade Federal de Uberlândia
Faculdade de Engenharia Mecânica

DISPLACEMENT FIELD ANALYSIS IN THE MANDIBULOTOMY TECHNIQUE USING THE FINITE ELEMENT METHOD

Thiago Caixeta de Araujo
Federal University of Uberlândia – João Naves de Ávila, 2160 – Campus Sta Mônica 1M – Uberlândia/MG
tcaixeta@mecanica.ufu.br

Cleudmar Amaral Araújo
cleudmar@mecanica.ufu.br

Sonia Aparecida Goulart Oliveira
sgoulart@mecanica.ufu.br

Sindeval José da Silva
Federal University of Uberlândia – Carajás, 701 – Lídice – Uberlândia/MG
sindeval@bol.com.br

Abstract. *The number of tumors in the oral cavity increased significantly, mainly, due to the use of the 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, cuts in the mandible in function of the tumor position and the condition of the patient can have different forms. The cuts fixation, in general, is made using miniplates and titanium screws or steel wires. This work aims to evaluate two types of cuts in a mandible, midline and paramidline, using different sets of fixation with miniplates. The simplified finite element models are used to determine the displacement of the contact surfaces and verify which type is better. The models are analyzed qualitatively with applied load, aiming to evaluate if problems with osteosynthesis will occur. These analyses allow the surgeon to evaluate, under the biomechanic point of view, the adopted surgical procedures.*

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

1. INTRODUCTION

Physicians have known head neck cancer since antiquity. 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) 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).

Mandibulotomy can be performed by 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 therapy. Median mandibulotomy can be further classified into midline mandibulotomy, which goes between the two 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 to minimize bone loss along the healing site (Amin et al, 1999).

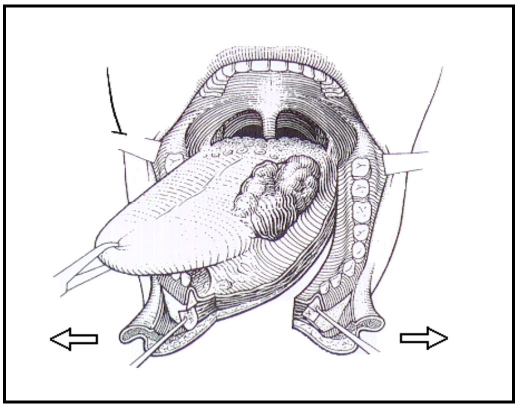
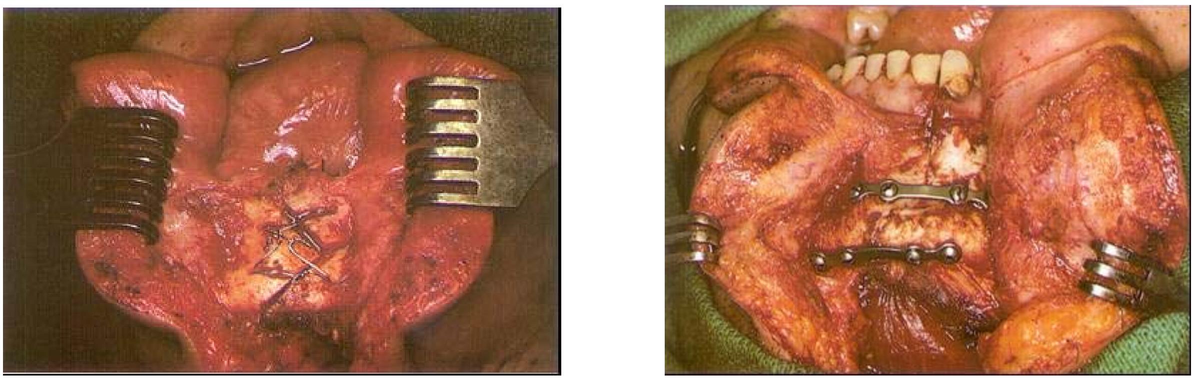


Figure 1: Mandibulotomy - tumor approach.

After tumor extirpation, it is necessary a new union of mandible sections. 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: Fixation modes: (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 several sets of fixation with miniplates. Until now, there is no data or study that show the ideal type and configuration of miniplate(s) to provide fixation of mandibulotomy. Rigid fixation keeps the surfaces together, without displacement, and does not generate high levels of stress. If the region 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 behavior 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 (40x30x10mm) that will be fixed with miniplates and pins, simulating the union of the parts with midline and paramidline mandibulotomy. Cancellous bone was not considered in this preliminary work. According to Pan et al (2003), paramidline mandibulotomy is performed with at least 15mm in length to straight vertical osteotomy. The models and its configurations of fixation had been analyzed 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 approximate and secure the mandible by surgeons. A model of miniplate has been built 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. Therefore, 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 (1mm thickness) and pins (ϕ2.2mm) are glued together as if it is the same material titanium.

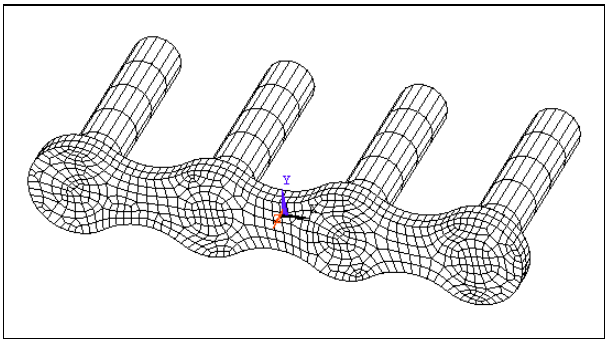


Figure 3: Finite element model of miniplate and pins.

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

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. Solid185 (Fig.4): 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.

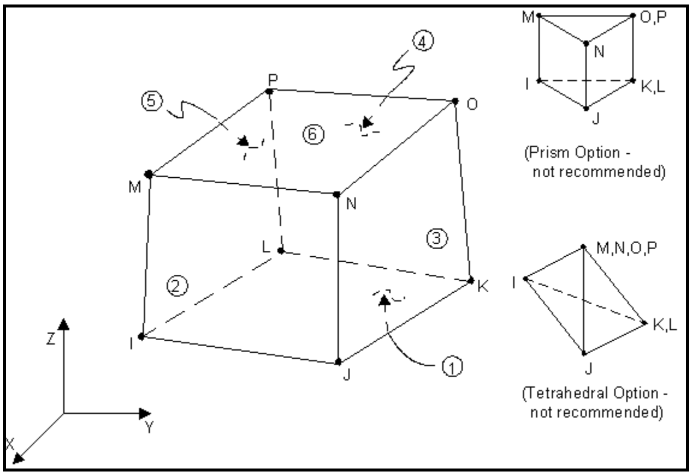


Figure 4: Solid185 element.

2. Targe170 (Fig.5): 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.

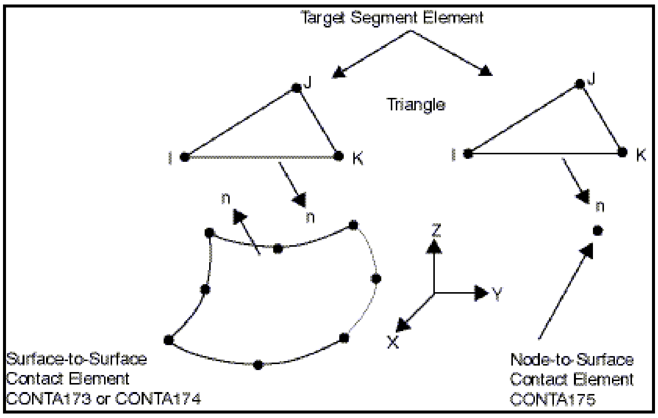


Figure 5: Targe170 element.

3. Conta174 (Fig.6): 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 contact surfaces are between the pins and bone, and the surfaces in the region of osteotomy. Contact problems can be analyzed as a particular case, such as, for example: in big structures with small regions in contact, this region can be analyzed separately. It is not necessary to solve the whole problem. Another study could be done varying the friction coefficient, although it is not our concern for a while.

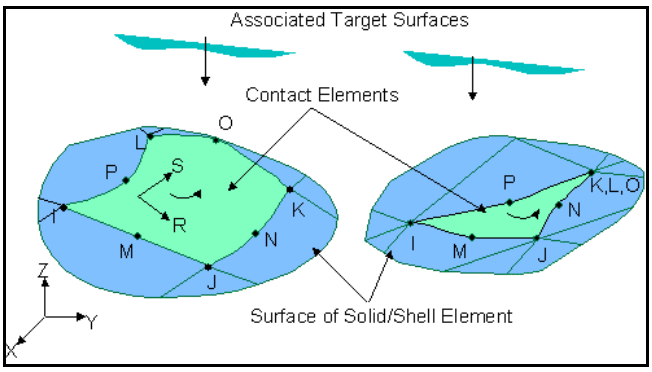
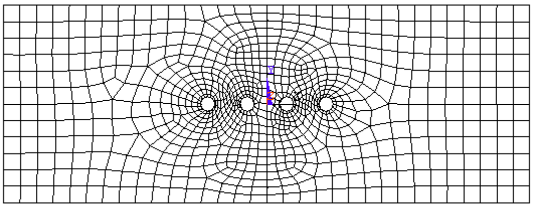
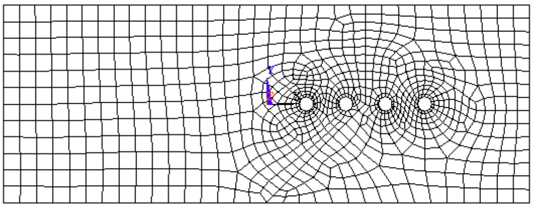
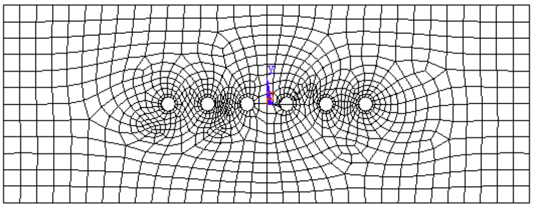
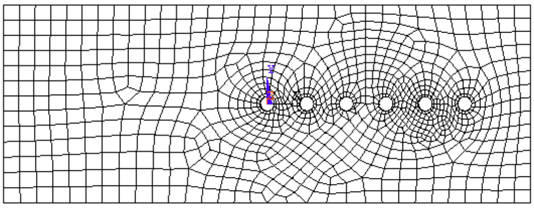
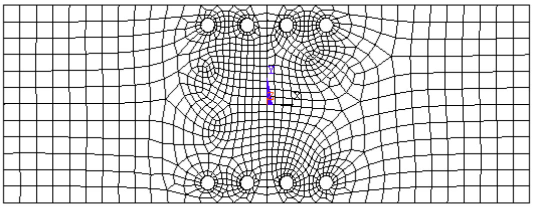
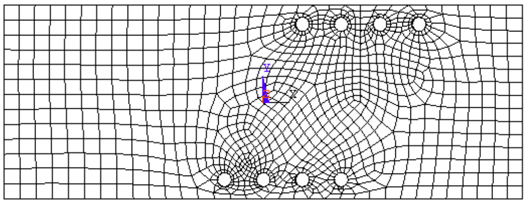
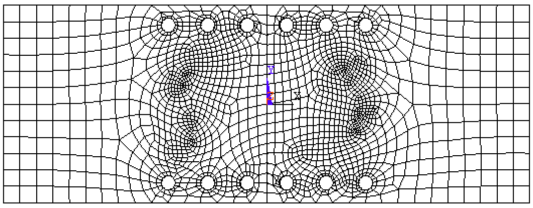
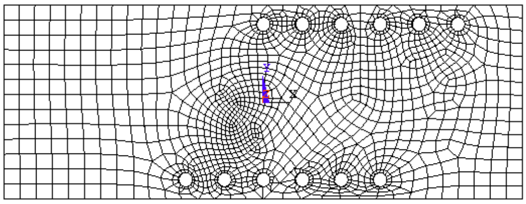


Figure 6: Conta174 element.

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

Table 3. Groups of the finite element models.

Models	Midline (M)	Paramidline (P)
1° *1 miniplate (4 holes)*	 4214 elements (5657 nodes)	 4164 elements (5615 nodes)
2° *1 miniplate (6 holes)*	 5084 elements (6749 nodes)	 4794 elements (6437 nodes)
3° *2 miniplates (4 holes)*	 5199 elements (7007 nodes)	 4879 elements (6665 nodes)
4° *2 miniplates (6 holes)*	 8719 elements (11363 nodes)	 6694 elements (10903 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 7 shows the mental region with one 1mm-miniplate placed in the mandibulotomy region. Thus, a pressure of 0.1 MPa was applied along the upper surface (80N distributed) and the nodes of the corner line were restricted as shown in Figure 8.

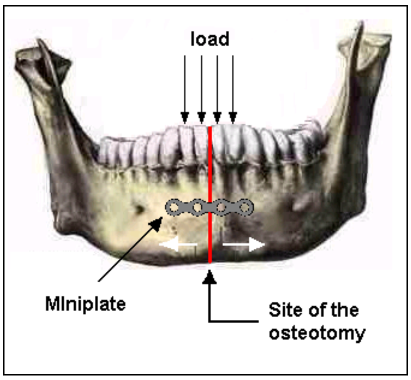
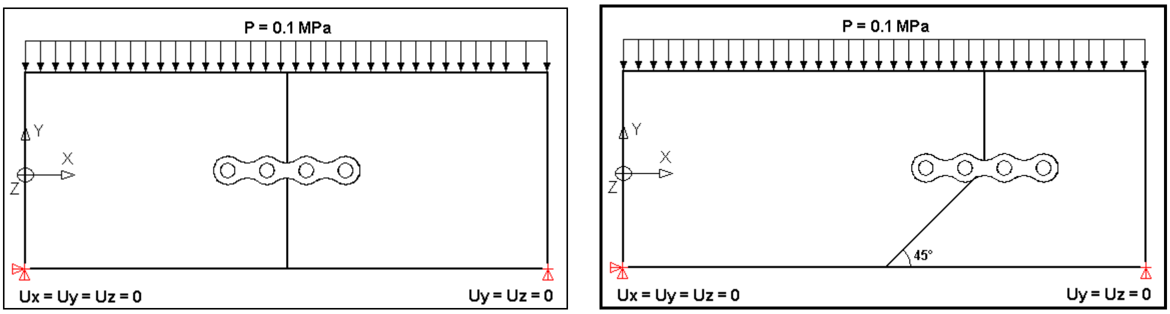


Figure 7: Occlusion in the central incisors with mandibular osteotomy.



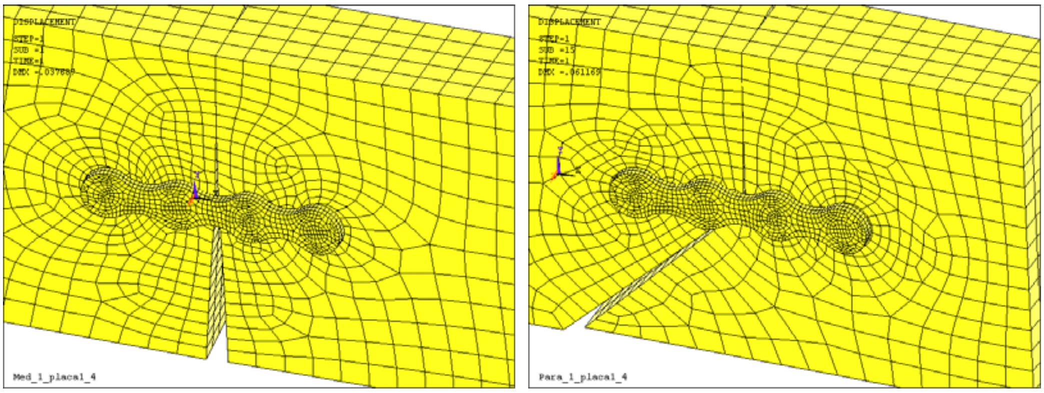
(a) (b)

Figure 8: Boundary conditions with midline mandibulotomy.

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

3. RESULTS

Figure 9 shows the first midline model (model 1M) and the first paramidline model (model 1P) in its deformed shape. The visible opening in the mental region causes concern to many surgeons, because it damages the osteosynthesis.



(a) (b)

Figure 9: Deformed shape: (a) Midline-1 miniplate (4 pins); (b) Paramidline-1 miniplate (4 pins).

Figure 10 shows the displacement in x direction between the osteotomy surfaces of the first group (midline mandibulotomy) and Figure 11 shows the second one (paramidline mandibulotomy), that it is the opening along the line of mandibulotomy. The y and z directions were rejected.

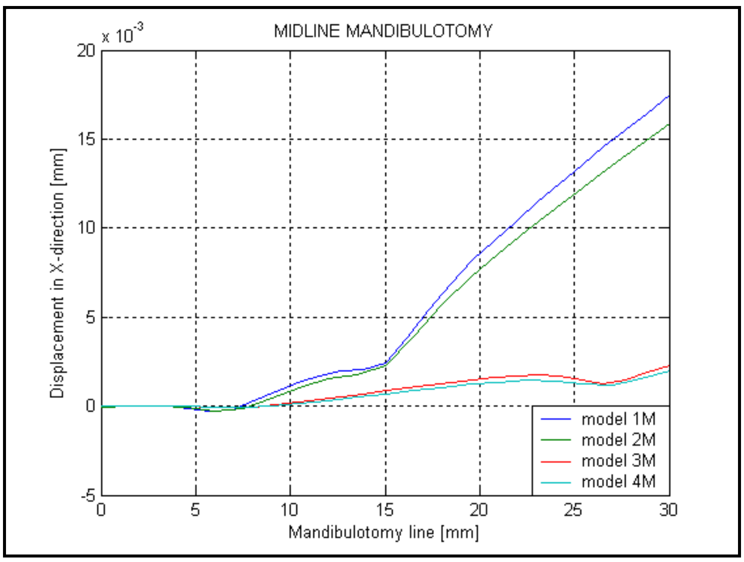


Figure 10: Opening in midline mandibulotomy.

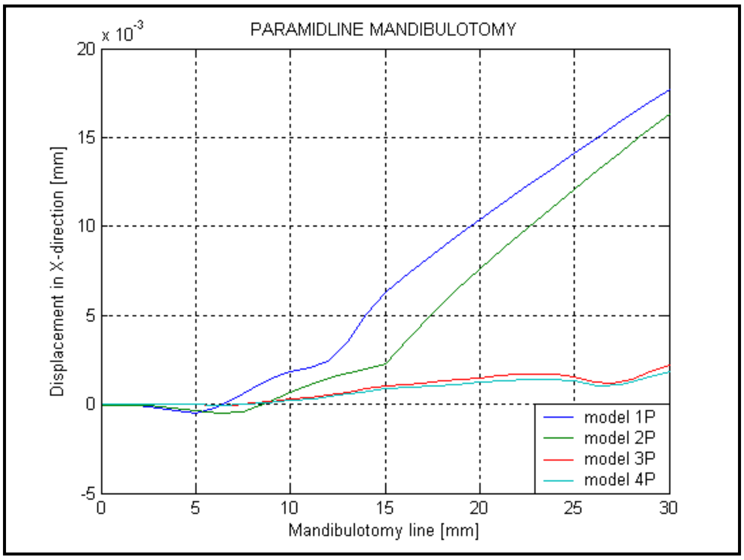


Figure 11: Opening in paramidline mandibulotomy.

Figure 12 and 13 shows Von Mises stress of the fourth model of midline (4M) and paramidline (4P) mandibulotomy, respectively.

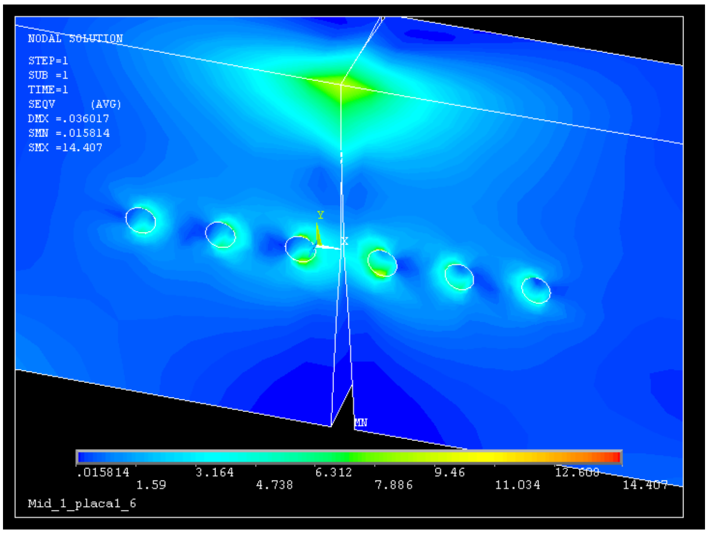


Figure 12: Von Mises stress in model 2M.

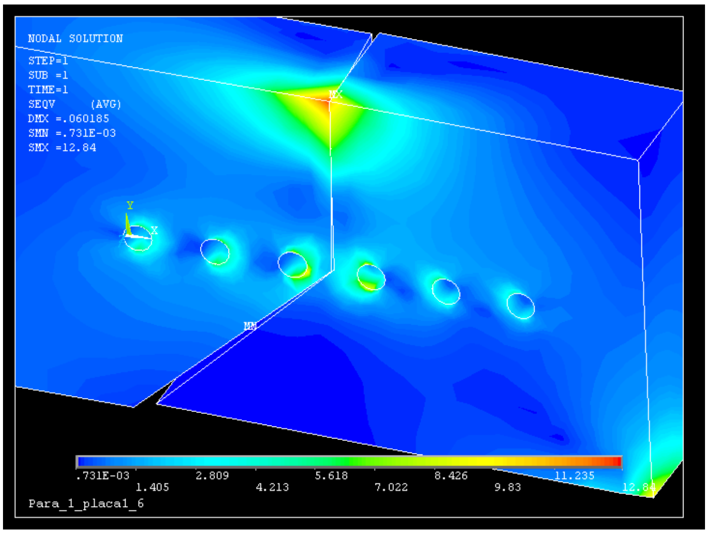


Figure 13: Von Mises stress in model 2P.

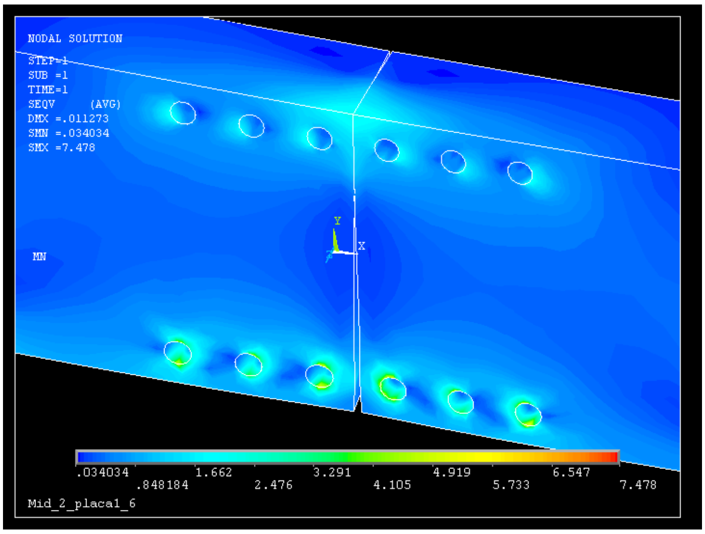


Figure 14: Von Mises stress in model 4M.

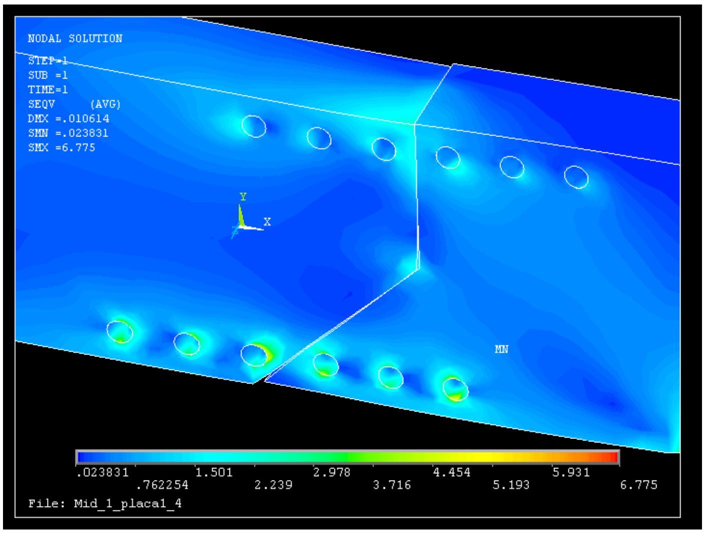


Figure 15: Von Mises stress in model 4P.

4. DISCUSSION

Complications associated with the use of rigid fixation techniques in mandibulotomy are close from the position of each miniplate. This study shows only one type of miniplate and four configurations of miniplate for each mandibulotomy. 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 it curvature and it will be possible achieve its influence.

The results show that the opening increase in the under mental region when one miniplate is placed. Figures 10 and 11 show that opening in both mandibulotomies are almost the same in all of them. It is noteworthy that the behavior of the models was near to each other. In all groups, the configurations that present less displacement are models 4M and 4P. But it is important to preserve bone for drilling holes less as possible. Then, the best way to obtain a rigid fixation and not lose bone is using two miniplates with 4 holes. Thus, we can affirm that these arrangements will warrant a faster osteosynthesis and wound healing. Whereas these configurations are considered as the best here, the surgeons do not place miniplates in dentulous patients, because it is possible to harm the incisors roots. If one miniplate must be used, we can say that the midline mandibulotomy is recommended. It has more favorable union along the osteotomy line than paramidline mandibulotomy. Along 20mm of the osteotomy line, the model 1M achieve better union than model 1P as demonstrated in Fig.10 and 11.

Figures 12, 13, 14 and 15 show the structural importance of using two miniplates configuration. Holes situated below the mental region are more requested than others. In majority of cases, the critical load occurs as shown in Figure 7, so this kind of modeling is reasonable. Holes have a bearing on distribution of stress, causing stress concentration and reabsorption. Outstandingly, we can verify a high stress level in upper side of mandibulotomy when one miniplate is used. This can harm the osteosynthesis.

All models generate small displacements. Thus, the main consequence of rigid fixation was achieved. Even these displacements can damage the bone union. Static load was applied instead dynamic load and the mandible has not a routine of static bites.

This work does not find great difference between midline and paramidline mandibulotomies. But, we used only one kind of boundary condition. Moreover, there are various miniplates and screws. Although with restrictions, this work gives a good conception of this structural problem.

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 to avoid delay of wound healing in patients. In this way, it must maintain the osteotomy surfaces 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 behavior. 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. Then, he can simulate any desirable response and 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 loading.

The next step is the modeling a real human mandible and gets the influence of its curvature.

Acknowledgments

We are gratefully acknowledge the financial support of CNPq and FAPEMIG.

6. REFERENCES

Amin, M.R., Deschler, D.G. and Hayden, R.E., 1999, *Straight midline mandibulotomy revisited,* Laryngoscope, Vol. 109, pp. 1402-1405.

Bathe, K.J., 1996, *Finite Element Procedures*, Prentice-Hall Inc., New Jersey, USA.

Brasil. Ministério da Saúde. Secretaria de Assistência à Saúde. Instituto Nacional de Câncer-INCA, 2002, *Falando sobre câncer da boca*, pp. 1-52.

Dai, T.S., Hao, S.P., Chang, K.P., Pan, W.L., Yeh, H.C. and Tsang, N.M., 2003, *Complications of mandibulotomy: midline versus paramidline*, Otolaryngol Head Neck Surgery, Vol. 128, pp. 137-141.

Dubner, S. and Spiro, R.H., 1991, *Median mandibulotomy: a critical assessment*, Head and Neck, Vol. 13, pp. 389-393.

Korioth, T.W.P., Romilly, D.P. and Hannam, A.G., 1992, *Three-Dimensional Finite Element Stress Analysis of the Dentate Human Mandible*, American Journal of Physical Anthropology, Vol.88, pp. 69-96.

McCann, K.J., Irish, J.C., Gullane, P.J., Holmes, H., Brown, D.H. and Rotstein, L.,1994, *Complications Associated With Rigid Fixation of Mandibulotomies*, The Journal Of Otolaryngology, Vol.23, pp. 210-215.

McGurk, M. and Goodger, N.M., 2000, *Head Neck Cancer and Its Treatment: Historical Review*, British Journal of Oral and Maxillofacial Surgery, Vol.38, pp. 209-220.

Menicucci, G., Mossolov, A., Mozzati, M., Lorenzetti, M. and Preti, G., 2002, *Tooth-Implant Connection: Some Biomechanical Aspects Based on Finite Element Analyses*, Clinical Oral Implants Research, Vol.13, pp. 334-341.

Pan, W.L., Hao, S.P., Lin, Y.S., Chang, K.P. and Su, J.L., 2003, *The anatomical basis for mandibulotomy: midline versus paramidline*, Laryngoscope, Vol. 113, pp. 377-380.

Shah, J.P. and Kowalski, L.P., 2000, *Cirurgia Cabeça e Pescoço*, Editora Revinter Ltda, 2ª edição.

Spiro, R.H., Gerold, F.P., Shah, J.P., Sessions, R.B. And Strong, E.W., 1985, *Mandibulotomy Approach To Oropharyngeal Tumors*, The American Journal Of Surgery, Vol. 150, Pp. 466-469.