FEA on Mastication Efforts During Osteosynthesis of a Fractured Mandible

ALINA ORMENISAN[1], MIHAIL TARCOLEA[2]*, MIRCEA SUCIU[1], RADU IONUT GRIGORAS[1], FELICIA GABRIELA BERESESCU[1], DANIEL VLASCEANU[3], VIOLETA HANCU[3], RALUCA-MONICA COMANEANU[3]

[1] Faculty of Dental Medicine, UMF Târgu Mureş, 38 Gh. Marinescu, 540139, Târgu Mureş, Romania

[2] Politehnica University of Bucharest, Faculty of Material Science and Engineering, 313 Splaiul Independentei, 060042, Bucharest, Romania

[3] Politehnica University of Bucharest, Faculty of Engineering and Management of Tehnological Systems, 313 Splaiul Independentei, 060042, Bucharest, Romania

[4] Titu Maiorescu University of Bucharest, Faculty of Dental Medicine, 67A Gh. Petrascu, 031593, Bucharest, Romania

The lower jaw is frequently exposed to fracture, by accidents, violence, accidental falls, sports injuries, pathological fracture, etc. We have investigated the behaviour of mandibular bone in a particular clinical case of fracture, in which we experimentally applied two osteosynthesis plates and analyzed the effects of occlusal loading on the fracture line by finite element method. We observed that in this case, maximum deformations occur in the mandibular condyles and the maximum and minimum normal stresses occur in the osteosynthesis plates. Even if bite and mastication determine important efforts on osteosynthesis plates, titanium alloy supports well these loads, and, as an important aspect, the bone parts during healing are not the object of excessive mechanical loads.

Keywords: FEA, mastication, osteosynthesis, fracture, mandible

The lower jaw is very prominent and vulnerable bone [1] due to its position being the most frequently exposed to craniofacial trauma. The causes of mandibular fractures [2, 3] can be: accidents, violence, accidental falls, sports injuries, pathological fractures, etc.

Proper management of mandibular fracture is essential to restore the patient occlusion and avoid serious complications and secondary operative procedures [4].

The different ways [5, 6] available for the treatment of mandibular fractures are:

(a) elastic or rigid intermaxillary immobilization;

(b) monomaxillary immobilization with oral rails;

(c) plate and screw osteosynthesis associated with intermaxillary elastic immobilization.

After Haug [7], mean values of mandible fracture in relation to location are distributed: 29% to the body of mandible, 26% at the mandibular condyle, 25 % at the mandibular angle, 17% in the symphysis and parasymphysis area, 4% in the mandibular ramus and 1% in the coronoid process.

Mandibular lateral fractures occur anywhere between the distal face of the canine and mandibular angle. Lateral fractures can occur either by direct or by indirect mechanism. Secondary movements may be important due to the action of antagonistic muscle groups with independent insertion on the two asymmetric bone fragments [8].

To optimize and planning of surgical therapy for mandibular fractures there are specialized software for the diagnosis, creating three-dimensional models and finite element analysis (FEA) of the tension arising at the interface bone-osteosynthesis plate during virtual application of masticatory forces.

Analysis by FEA is particularly useful in detecting risk areas [9], giving us the possibility to study the distribution of stresses and strains of a mechanically loaded structure [10].

Mimics® (Materialise's Interactive Medical Image Control System) and 3-matic®, Copyright Materialise NV, are software that allows processing medical image to create 3D models and allow correlation with rapid prototyping systems (RP), computer aided engineering (CAE), computer aided design (CAD) and surgical planning [10].

Experimental part

We have investigated the behavior of mandibular bone in a particular clinical case of fracture, in which we experimentally applied two osteosynthesis plates and analyzed the effects of occlusal loading on the fracture line by finite element method.

We selected a patient, 48 years old, with craniofacial trauma produced by hetero-aggression that led to the lateral mandible fracture; the fracture line is between the corresponding edentulous ridge of 46 tooth and reaching basilar edge of mandibular bone (lateral fracture with total dislocation in all three planes). We initially processed the mandible, simulated the mandible parts repositioning, and placed the two osteosynthesis plates using Mimics®, then finished triangles mesh of the 3D structure (mandible parts and plates) with 3-matic®, and finally we made the simulation of occlusal loading in ANSYS®.

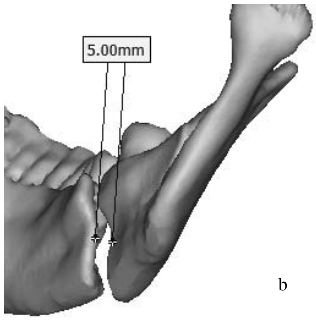
After loading in Mimics® the images provided by CT scan, we virtually separated the mandibular fractured bone from the rest of viscero-cranium bones (fig. 1a) and we made measurements of the gap produced by the trauma movement of the fractured fragments (fig. 1b).

After alignment of the fractured bone fragments in Mimics® and experimental application of osteosynthesis plates, with the necessary remeshing in 3-matic®, we have imported the created model components in ANSYS®

* *email: mihai.tarcolea@upb.ro; Tel. 0730159122*

a

Fig. 1a. Initial situation of the patients case



b

Fig. 1b.Gap between the fractured fragments

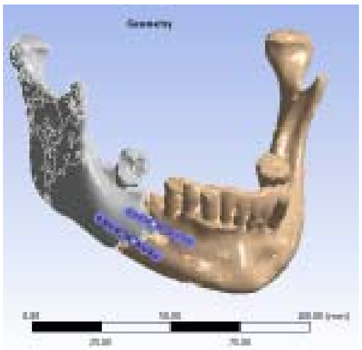


Fig. 2. Geometry of the model in ANSYS

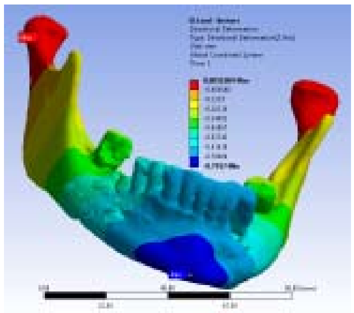


Fig. 3.Model deformation on Z loading axis for bite

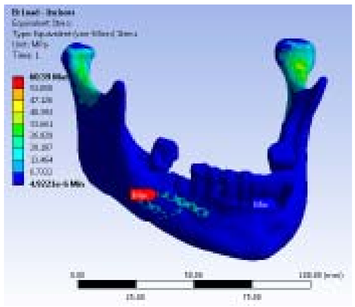


Fig. 4. Equivalent stress (von Mises) distribution in the model for bite

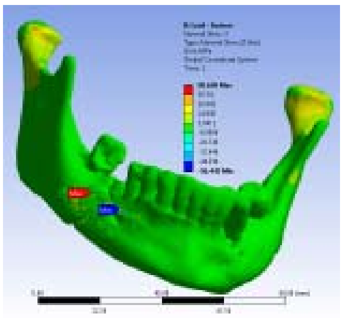


Fig. 5. Normal stress distribution in model on OZ axis for bite

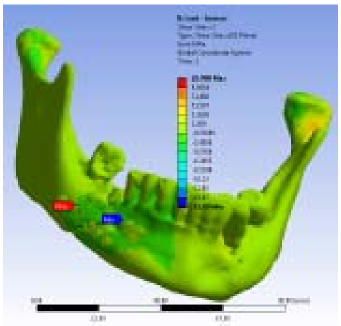


Fig. 6. Shear stress distribution in the model in XZ plane for bite

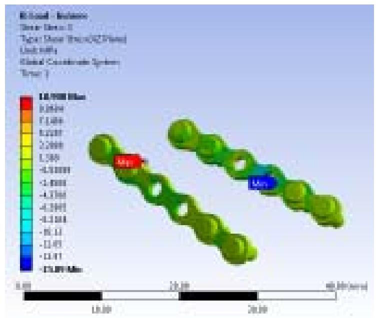


Fig. 7. Shear stress distribution in the plates in XZ plane for bite

(fig. 2) in order to perform numerical analysis to evaluate the mechanical behaviour of bone-plate assembly.

The aim of the analysis was to determine the tension and deformation of osteosynthesis plates and mandibular bone.

In order to make the numerical simulation we used the following material properties [11]:

-for osteosynthesis plates (titanium alloy): Modulus of Elasticity (Young) E = 96000 MPa and Poisson's Ratio ν = 0.36;

-for patient bone: longitudinal elastic modulus value that we assigned is E = 17 GPa, Poisson's Ratio ν = 0.4, Tensile Strength at Break σ_{rt} = 49-148 MPa, Compressive Strength $\sigma_{r\ compr}$ = 131-205 MPa, Shear Strength τ = 65 MPa.

The considered masticatory force was of 150 N and was applied as uniform distributed pressure on the incisors for bite and on premolars and molars for mastication analyses. Due to patient asymmetric edentation the mastication effort was applied only on the right side of the mandible.

The next step in the analysis was to setup the conditions for support (attachment) and load (application of external loads for bite – on incisors, and for mastication – on premolars and molars).

Analyses performed were Static Structural type and through them we sought to determine the comparative state of tension in the entire model and movements resulting from external loading.

Results and discussions

Bite stage analyses

Figure 3 illustrates the distribution of distortion pattern in the direction of loading force application in bite case, resulting from numerical calculation.

It can be seen that the deformation of the structure is between a compression strain of 0.794 mm and a tensile strain of 0.005 mm (tensile strain), the extreme compression strain being located at the menton, and the extreme of tensile strain in the condyles. At the outbreak of fracture, the compression strain is of about 0.5…0.6 mm.

Figure 4 shows the equivalent stress distribution (σ_{ech}) calculated according to von Mises criterion. The maximum value of 60.59 MPa is located at distal screw of the upper plate and the minimum value of 4.9×10^{-6} MPa is found in the vestibular cusp of the 34 tooth. Throughout the length of the two osteosynthesis plates we meet equivalent stress contained in the range 6.7…20.2 MPa.

On OZ axis, normal stress ranges from -56.4 to 50.6 MPa, both the maximum and minimum recorded in the upper plate. These tensions with different sign could induce a rotation tendency between mandible elements (bone and plate) (fig. 5).

Regarding share stresses registered in the XZ plane (fig. 6), we found a variation between 10.99 MPa (registered in the lower plate) and -15.89 MPa (in the upper plate).

The plates undergo these extreme values which are well supported by their material.

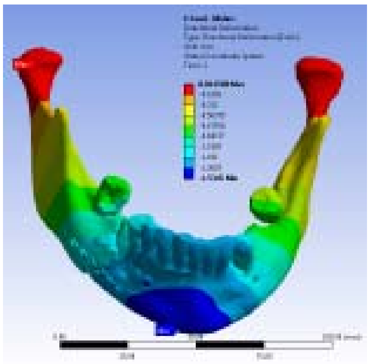


Fig. 8.Model deformation on Z loading axis for mastication

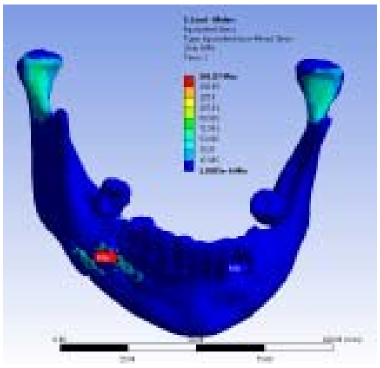


Fig. 9. Equivalent stress (von Mises) distribution in the model for mastication

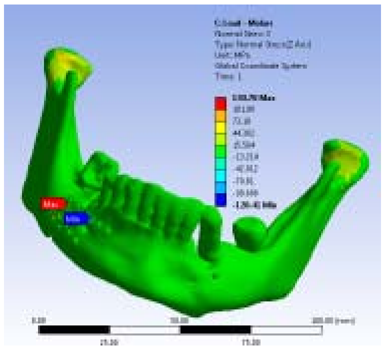


Fig. 10. Normal stress distribution in model on OZ axis for mastication

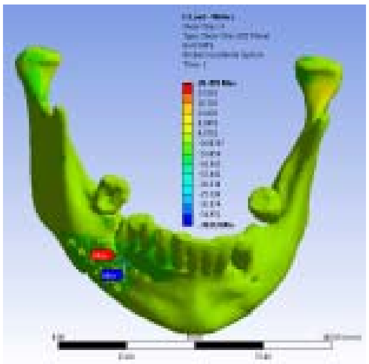


Fig. 11. Shear stress distribution in the model in XZ plane for mastication

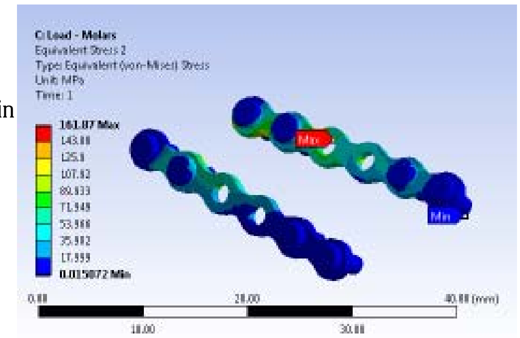


Fig. 12. Shear stress distribution in the plates in XZ plane for mastication

Mastication stage analyses

Figure 8 presents the directional deformation in the direction of loading force application in bite case (load applied on premolars and molar, corresponding to patient specific teeth configuration).

In this case the range is between a compression strain of 1.535 mm (in the menton area) and a tensile strain of 0.12 mm (in the mandible condyles).

The equivalent stress (σ_{ech}) range is now larger (fig. 9), from 161.87 to 1.04×10^{-6} MPa, with similar zonal distribution as in the bite case. The maximum of 161.87 MPa is located very close to fracture limit. The plates support values are in the range of 18…54 MPa.

Normal stress on Z axis ranges from -128.4 to 130.8 MPa, with both extreme values in the upper plate (fig 10).

Shear stresses resulted in the XZ plane (fig. 11) are in the range -39.83…28.46 MPa; the extreme values are found in the upper plate, but similar, even if smaller, are observed also in the lower plate.

In mastication case, the plates undergo these extreme values which are also well supported by their material (fig. 12).

Conclusions

In these analyses we observed that in the particular case of fracture under study, maximum deformations occur in the mandibular condyles and the maximum and minimum normal stresses occur in the osteosynthesis plates.

Maximum shear stresses in the XZ plane is recorded in the upper osteosynthesis plate and the minimum value is detected in the edentulous ridge for bite, and for mastication both extreme values are located in the upper plate.

In the bite stage both plates are loaded with extreme values, with different sign, determining a momentum applied to the mandible parts, but during mastication the extreme values, with the same sign, are located in the upper plate, even if also lower plate supports similar efforts with little values.

Even if bite and mastication determine important efforts on osteosynthesis plates, titanium alloy supports well these loads, and, as an important aspect, the bone parts during healing are not the object of excessive mechanical loads.

Acknowledgement: All authors have equal contributions to the study and the publications. This paper was partially sustained by the CIGCS-CC 2013 University of Medicine and Pharmacy of Târgu Mureş project, contract number 18/2013.

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Manuscript received: 16.03.2015