Computer Assisted Osteosynthesis for Mandible Fracture in Pathological Bone by Means of Finite Element Method

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The maxillo-facial reconstructive surgery very often uses regular shape biocompatible material plates which are fastened by screws to the rest of the bone. The choice of optimal plate for each case, especially in risk cases, should be made primarily according to surgeon medical experience but also following a strength analysis of the various existing plates. The analysis of mechanical structures by using the finite element method highlights the resistance, the risky areas in case of possible demands such as the jaw's pressure on the mandible, allowing the physician to optimize the restorative solution.

Keywords: finite element, osteosynthesis

The maxillo-facial reconstructive surgery very often uses regular shape biocompatible materials plates which are fastened by screws to the rest of the bone. Thanks to a close and lasting contact between fragments maintained close under pressure, bone callus forms rapidly significantly shortening the healing period. The plates provide an excellent tridimensional stability without risk of relapse until bone callus formation. They also constitute a good support for interfragmentary bone transplants in reconstruction of fracture with loss of substance[1].

The choice of optimal plate for each distinct case, especially in risk cases, should be made primarily according to surgeon's medical experience but also following a strength analysis of the various existing plates (geometry and material) for the concrete situation that needs to be solved[2].

Experimental part

In the case of reconstructive surgery for a patient with pathological bone lesion in the mandible, inmate at the Maxilo-Facial Surgery Hospital, the question of using a regular biocompatible plate attached by screws to the rest of the bone to become support for osteosynthesis appeared. For the type of plates used in such cases there were three thicknesses available. The areas for applying the screws in order to secure the plate are the girders or strength pillars where the compact bone is more abundant and the bone thickness is higher. Correct and accurate placement of screws is one of the most important steps in securing and for the conduct of the plate, and thus the fracture fixation[3] and it depends on the bone tender of each distinct case. Screws fastening points are points of the plate's support and their position is crucial to the mechanical stress in the plate. The material from which the plate is made is a titanium alloy. There are several solutions of the alloy [4], the ones with the maximum biocompatible qualities have generally lower strength characteristics.

In order to clarify the type of lesion, its localization and exact extent, native computer tomography of the head was performed, sections with a slices density of 1/cm. In order to avoid overexposure to roentgen radiation, a section of skull showing only basic bone lesion was scanned. Profile radiography of the mandible has also been done (fig. 1).

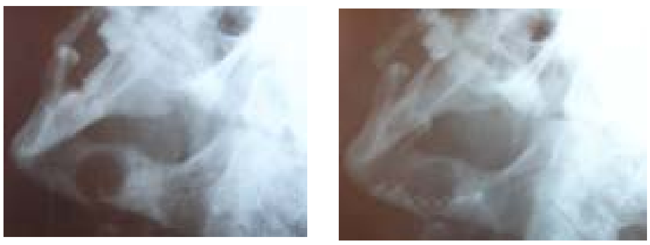

Fig. 1. Radiography of left mandibular section

The type and form of the biocompatible plate used in such cases is shown is (fig. 2). We considered necessary to perform an analysis that shows the status of stresses and strains that occur in the plate, for three different thicknesses 1, 2 and 3 mm, which could be used. This analysis was performed using finite element analysis method, by using ANSYS software [5].

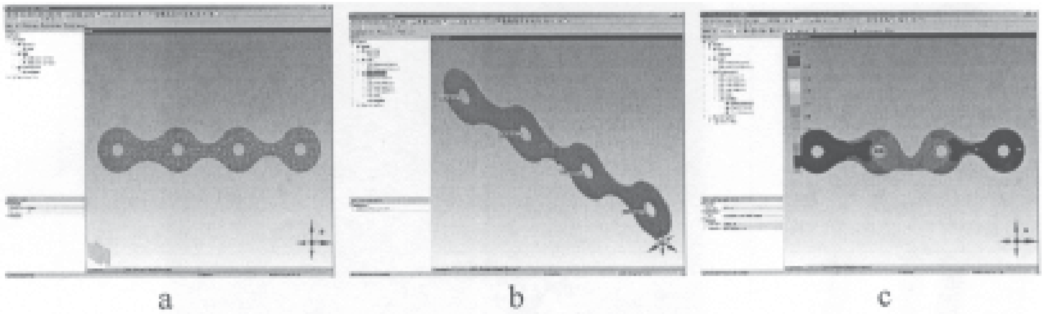

Fig. 2a. Decomposition by knots and elements; b-constraints on screw fastening points and the pressure forces on the plate; c-the distribution of stresses

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We took into account the possibility of severe stress such as the jaw pressure on the mandible, by accident, because normally it should not be allowed [6]. Applying the method involved the following steps:

- retrieving the existing plate geometry for each distinct thickness as well as the bone tender (offer) where the screws can be placed as resulting from the computer tomography scan;
- generating knots (nodes) and finite elements;
- specifying the constraints on the plate and the forces applied on it.

Since the plate is bolted to the bone, the locations of clamping screws impose fixed support conditions[7]. On the other hand because of the forces developed, during mastication, occured along the line of fracture, it is necessary to apply a force in the plane of the plate. The value chosen is 600 N, this being the maximum value for the process of mastication , and near maximal in exceptional cases of blows/shocks[8].

The titanium alloy, the plate is made of, has the following mechanical characteristics:

- elasticity module is 1 . 105 N / mm^{-2} or 1 . 10^{11} Pa
- the tensile (stress) strength is 1200 N / mm^2 meaning 1200 . 10^{-6} Pa
- the maximum relative deformation is 6%

As a result of applying the boundary conditions, the body receives the action of a force described by the following vector:

[2.83 . 10-14 N x, -600.0 N y, 0.0 N z], and of two reaction forces in the fixing points of 288.09 N and 312.75 N respectively, as described by the following vectors:
[-15.86 N x, 287.65 N y, 2.21×10-3 N z], [15.86 N x, 312.35 N y, -2.21×10-3 N z]

In the above relations, x, y and z represent the directions of the Cartesian system Oxyz axes.

The last step is the finite element analysis (fig. 2).

Results and discussions

Following the finite elements analysis, it is shown that the efforts in the first 1 mm thick plate exceed the acceptable limits, the efforts in the 2mm thick plate are within acceptable limits while the 3mm thick plate would be oversized in the given situation.

The titanium 2mm thick plate was chosen and the following results were achieved:

- the minimum equivelant stress (tension) is 94.716.96 Pa, and the maximum is 7.61 . 107 Pa
- the main maximum stress (tension) ranges between -500,150.22 Pa and 4.85 . 107 Pa
- the relative equivalent deformation ranges between 9.87. 10^{-7} m/m and 7.92 . 10^{-4} m/m
- the total minimum deformation is 0.0 m and the maximum is 2.54 . 10^{-5} m

In the terms analysed, namely normal use, the plate functions well, strongly fastens the bone without essential deformation which could affect the fracture.

Conclusions

The article highlights the result of a complex interdisciplinary design work situated at the frontier between engineering and medicine, with applications in the biomedical field.

The use of titanium alloy biocompatible plates of regular shape in the reconstructive maxillo-facial surgery directly on the bone fixed with screws at each end of both bone segments of the fracture is beneficial for ensuring the functionality of the broken jaw. They can be removed after the bone has healed or can remain permanently attached to the bone.

The analysis of mechanical structures used for bone reconstruction with the finite element method highlight the endurance tether, the risk areas in case of potential stress such as the force of jaw pressing on the mandible, allowing the physician to optimize restorative solution.

Future prospects are tied to the development of dedicated software applications based on the finite element method, to allow the surgeon to analyze in real time the possible solutions, taking into account both dimensional and material related variants but also the real possibilities of fastening the screws depending on the bone offer that varies from case to case[9].

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