Personalized anatomically adjusted plate for fixation of human mandible condyle process

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***Abstract*— Due to its position and anatomy, human mandible is sensitive to trauma. Fractures of the mandible are different by type, origin (e.g. injuries, tumors), localization (eg. collum, the ramus, angle of mandible, the body of the mandible and alveolar part). Various types of implants are used for the fixation of human bones fractures. Anatomically correct and geometrically accurate personalized implants are necessary in order to improve the quality and duration of the intervention, and postoperative recovery of patients. The aim of this research is to create a geometrical model of the personalized implant plate type which geometry and topology fully matches to the shape of the bone of the patient. The side of the implant, which is in contact with a periosteum outer layer of the mandible, is aligned with the shape of the mandible's outer surface near the fracture. The obtained model can be used for production of plate implants, and/or for simulation of orthodontist interventions.**

I. Introduction

The human mandible (*lat. mandibula*) is the most prominent and the only movable facial skeleton bone, which is the most sensitive to trauma. The fractures of the mandible are frequent, difficult and complicated, incurred as a result of illness and injury. In treating fractures, it is a great responsibility of doctors to establish the normal function of bone tissue and return the aesthetic appearance of the injured to the previous state. Treatment of fractures of the mandible depends on the patient's age, the type of fracture (single, double, open, closed), loss of bone tissue and anatomical localization (the body of the mandible, ramus ...), the clinical experience of the surgeon and the patient's general condition [1]. Maxillofacial surgeons apply internal and external fixation for the treatment of fractures of the mandible. Internal fixation is a surgical technique used to support the treatment of bone fracture using screws, pins and plate implants within the human body. The external fixation is used to stabilize bone fragments outside of the human body. With this type of fixation within the human body only pins and screws are placed.

Attempts to successfully treat bone fractures have existed since the ancient times. Advances in understanding of the anatomy and histology influenced the development and progress of various techniques of bone fracture treatments. The main principles that must be met during medical interventions in surgery for fixing broken bones are fixing the broken fragments in anatomical position, stable functional fixation, a traumatic surgical technique and active function.

Treatments of the mandible fractures are changing from decade to decade, but there are still controversies regarding the optimal treatment. Rigid internal fixation can be achieved by a variety of plating systems. Types of plates include: mandible plates 2.0, locking plates 2.0, (Locking) reconstruction plates, dynamic compression plates, universal fracture plates [2]. The mentioned types of plate differ in shape, length, thickness, the use of screws (standard, locking head, Bio-Cortical), as well as different biomechanical stability.

Mandibular condylar fractures are one of the most common injuries of the facial skeleton. In literature, the injury of human condylar neck is usually treated with a single mini dynamic compression plate or with double plates. The use of a single plate for fixation of fractures of the condylar neck is the most common, although the authors point to complications concerning fracture plate or screw loosening [3,4].

The analysis of retrospective studies on the treatment of patients with fractures of condylar neck with single and double plates indicates that the use of double plate provides greater stability and fewer complications than the single plate [5].

By comparing three different fixation techniques of the mandible condyle, the authors confirmed that the technique of using two plates provides a stable and functional fixation of the human mandible condyle [6]. "This is primarily due to the ability to neutralize the functional stress imposed on the neck of the mandibular condyle through the arrangement of the 2 plates".

Very often the use of standard pre-identified implants can lead to intra-operative and post-operative complications in the patient. Complications occur as a result of differences in the size and shape of the patient's bone and the implant plates. Poorly positioned implant plate, causes an inadequate transfer of load during the healing process of bones, which makes the treatment more difficult. Also, one of the disadvantages of this method of fixation is the duration of the intervention. During the intervention maxillofacial surgeon devotes a lot of time shaping and bending a standard plate to adjust it to the patient.

In order to lessen the above mentioned complications, the authors suggest the application of personalized implants. Personalized implants allow for proper stabilization of broken fragments, and better adapt to oblique fractures. The geometry and shapes of the personalized implant is adapted to the anatomy and morphology of a certain patient [7].

According to statistics, about 36% of the mandible fractures occur in the condylar region, which also represents the highest percentage of incidence of all mandibular fractures (according to Dingman and Natvig). For this reason, main focus of this research is creating implants for fixation of human mandible condyle process, which varies in shape and size, and needs to be adjusted to the patient’s specific needs. The quality of the geometric model of the implant depends on the 3D surface model of the mandible. The side of the implant, which is in contact with a periosteum outer layer of the mandible, is aligned with the shape of the mandible’s outer surface near the fracture. In this way, the geometry of the implant corresponds to the patient's bone. The surface model of mandible was created in CAD software CATIA reverse engineering techniques. Geometrical accuracy of the obtained surface model of plate implant was tested by the application of the deviations analysis in CATIA software.

II. DESIGN OF CUSTOMIZED IMPLANTS TYPE PLATE FOR MANDIBLE FIXATION

The steps used to create the volumetric geometrical model of plate implant are [8]:

1) CT scan of the specific patient mandible
2) Creating a 3D surface model of mandible
3) Creating a model of a fracture
4) Selecting the locations on the mandible where the implant will be placed
5) Adjusting the geometry of the plate according to the requirements of the surgeon
6) Creating a customized 3D model of the plate
7) Analysis and optimization of the shape and dimensions of plate.

Geometry analysis of the human mandible is realized on CT scans. 64-slice CT scanner was used (MSCT) (Aquillion 64, Toshiba, Japan), and standard protocol for recording was applied: voltage of 120 kVp, tube current of 150 mA, rotation time of 0.5 s, and thickness of 0.5 mm. The mandible sample came from a Serbian adult male aged 45 years. The raw data, coordinates of points of scanned tissue, were imported into the appropriate CAD software for reverse modeling. In this research CATIA V5 R21, CAD software was used. Scan of mandible was without fracture, and model of fracture defined by standard classification [2] was created to the mandible model in the later stage of the reconstruction process.

A. *Creating 3D surface model of the human mandible*

3D surface model of human mandible is created in CATIA, using Methods of Anatomical Features (MAF) [9]. The steps that used to create surface model of the mandible are [10]:

1) Creation of the anatomical model
2) Preparatory processes (Importing and sorting out the cloud of points, creating a polygonal model)
3) Definition of the Referential Geometrical Entities (RGE) of the human mandible
4) Definition of the anatomical points and creation of the spline curves
5) Creation of the surface model of human mandible.

Creation of the anatomical model

Anatomical model "describes" relations between anatomical landmarks (which can be taken from medical literature) and their position on the polygonal model [8].

Preparatory processes

Preparatory processes include the following: CT scanning of the human mandible, preprocessing of raw data (scans), their transformation into STL (STereoLithography) format, importing the scanned models in STL format into CATIA application. At the end of the preparatory processes the polygonal geometrical of the human mandible model is created.

Definition of the Referential Geometrical Entities (RGE) of the human mandible

MAF is based on Referential Geometrical Entities (RGEs). RGEs (lines, planes, curves, points, axes) are defined on polygonal model, according to the bone geometry and morphology [11].

Every bone in the human skeletal system has distinctive features that describe it. On the human mandible the following characteristic of anatomical pointscan be extracted and defined: Mental Foramen, Gnathion, Gonion, Condylion and Mandibulare cut [12]. In the same paper, authors stated that the configuration of the mandible can be accurately perceived by means of ten (10) basic central and bilateral morphometric parameters. Morphometric parameters are measurable dimensions, determined on the basis of the position of the characteristic anatomical points. Definition of the mandibular anatomical landmarks and morphometric parameters were performed on a polygonal model of the human mandible.

The first step in definition of the geometrical model is the creation of Coordinate system which is used for identification of RGEs, on polygonal model.

Origin of the coordinate system was positioned at the middle point of the distance between the most lateral points on the two condyles. The constructed planes of the Coordinate System of the mandible are: Mediosagittal, Mandibular and Coronal. A detailed description of constructed planes of the Coordinate System is given in [13].

Definition of the anatomical points and creation of the spline curves

The spline curves (geometrical entities) were defined following the bone geometry and its specific morphology Spline curves were created by the cross section of the adequate planes and polygonal models. Based on the

Medio-Sagittal plane (rotated to the right angle), sixteen planes were created which have been used to create cross-sections. At the intersection of these planes with polygonal model, contour curves are generated. These curves are used to create points and spline curves. The same procedure, was applied for creation of 3D surface model for the body and ramus of mandible (Fig.1). A detailed description of creation of the spline curves on mandible ramus and body is given in [13].

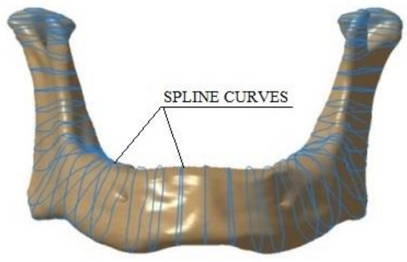


Figure 1. Spline curves on a polygonal model of the human mandible

Creation of the surface model of human mandible

3D surface of the human mandible is created by merging 3D surface of mandible body and ramus (Fig. 2).

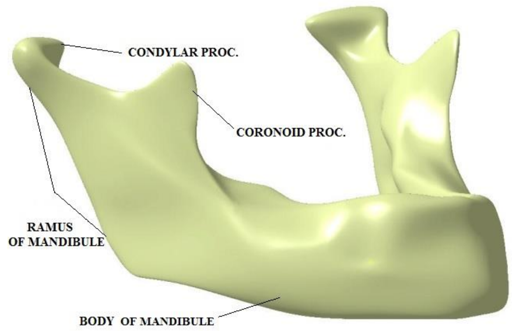
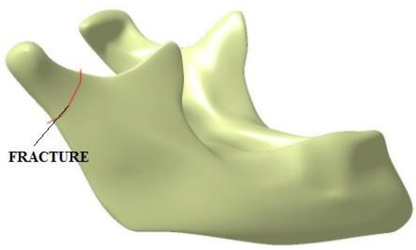


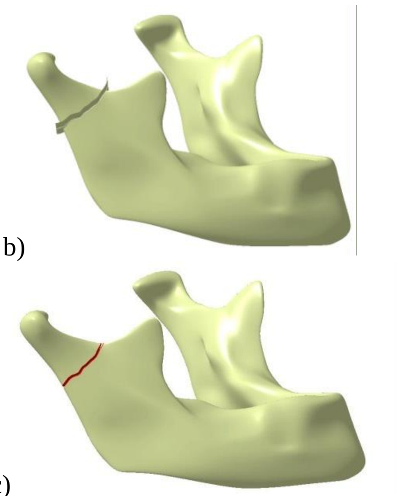
Figure 2. 3D surface model of the human mandible

B. Creating 3D model of fracture

One of the initial steps in creating a 3D volume model of personalized plate implant is creating a 3D model of fracture. A simple fracture is created in accordance with the AO Classification [2], in cooperation with maxillofacial surgeons. Process of creating 3D model of fracture is shown on the Fig. 3. The 3D model of fracture is created on the surface model of the human mandible, using appropriate engineering techniques for free form surface and spline modeling.



a)



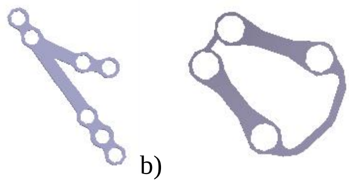
b)

c)

Figure 3. Process of creating 3D model of fracture

C. 3D model of customized implant

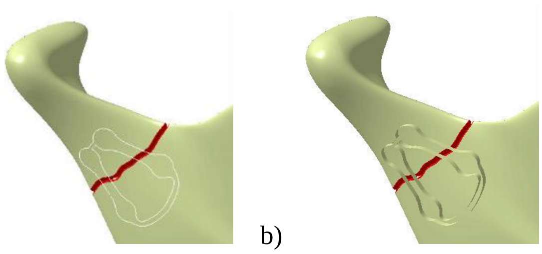
Close to the model of the fracture, a datum plane, not far from the lateral surface of bone, is created. Plane is placed opposite the contour of the fracture. In cooperation with maxillofacial surgeons, implant of plate type has been selected, for fixing condylar fracture. The proposed implant has a shape of a trapezoid. For this type of fracture of the condyles we can also find a plate type of implant shaped as letter L (Fig. 4a). Elements of this type of fixation completely follow the shape of the human mandible, but the duration of the operation takes longer due to the greater number of openings in the plate. Moreover, the stability of fixation is less certain than with the trapezoid model since the elements of fixation are not interconnected.



a) b)

Figure 4. Shape of the personalized plate implant

Outer contour of the proposed implant is drawn on this plane, and projected onto the surface of the bone (Fig.5).



a) b)

Figure 5. Outer contour of the implant

Spline curves were created in the area limited by the created contour, and every single spline curve follows the shape of the mandible surface model. The surface of plate implant was created by the application of these curves.

The volume model of plate implant is created by the extrusion of the surface normal to the created datum plane. Process of creating of the 3D volume model of the personalized plate implant is shown on the Fig. 6.

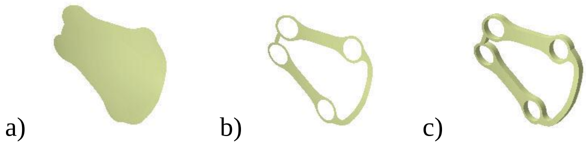


Figure 6. Process of the creating of the 3D volume model of the personalized plate implant

After the plate has been shaped, the creation of the screw holes on the proximal side of plate part is performed. System of screw holes was created on the volume model (Fig.7).

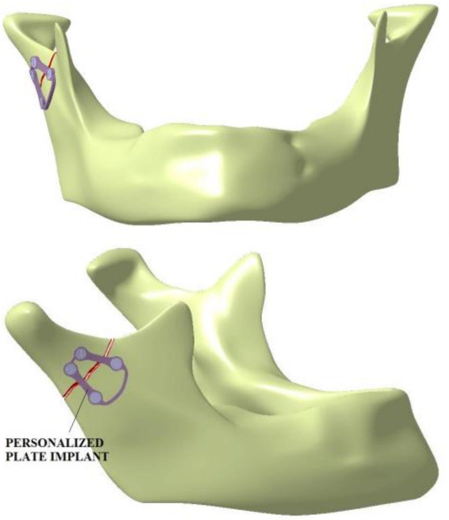


Figure 7. Mandible fracture fixation

III. RESULTS

Geometrical accuracy of the obtained surface model of the personalized plate implant was tested by the application of the deviations analysis in CATIA software.

Maximum surface deviations of the surface model of the personalized plate implant from the input human mandible model are presented in Figure 8. It can be noticed that deviation value is also below the recommended limit. Geometrical accuracy of the obtained surface model in accordance with the reference values from the literature [14]. This means that the quality of the resulting surface model of the personalized plate implant is aligned with the shape of the mandible's outer surface near the fracture.

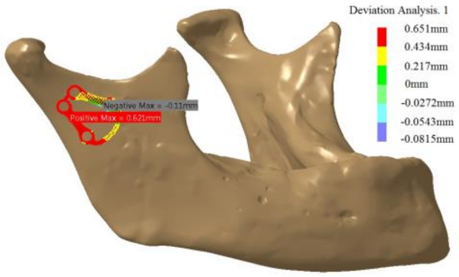


Figure 8. Maximum deviations of the surface model of the personalized plate implant from the input human mandible model

The presented method has enabled the creation of 3D personalized plate implant for fracture fixation of the human condyles, which can be used for further production. Figure 9 shows the printed model of the personalized implant plate.

Figure 9. Mandible fracture fixation

IV. FURTHER WORK

Further work by the authors of this study will be based on an attempt that the personalized plate implants created in this way be a part of the standard procedure in carrying out interventions in maxillofacial surgery in Nis. The authors of this study (a team of engineers) and maxillofacial surgeons at the Clinical Center in Nis have already had joint cooperation that yielded good results. The procedure was a correction of the mandible in patients with congenital deformity (prognathism), where the printed personalized models were used as standards by which they bent the appropriate fixators intended for the intervention itself. With the joint cooperation of maxillofacial surgeons and engineers, the quality of preoperative planning and course of intervention have increased, and the duration of the intervention has reduced.

V. CONCLUSION

The method presented in this study enable creation of 3D geometrical model of the personalized implant plate type for the fixation of human mandible fractures. The geometry and shapes of the personalized implant is adapted to the anatomy and morphology of a specific patient. The side of the implant, which is in contact with the outer layer of the mandible, is aligned with the shape of the mandible's outer surface near the fracture. The obtained model can be used for production of plate implants, and/or for simulation of orthodontist interventions.

This process can be applied to create different plate implant for any other bone in the human skeletal system.

The created 3D model of plate implant is ideal for 3D printing or production.

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