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Chapter 1
Implants of the temporomandibular joint

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Abstract: Disorders of the temporomandibular joint are the result of degenerative diseases of the musculoskeletal system associated with morphological and functional deformities. Joint reconstruction is indicated in patients in whom conservative treatment has failed and a significant proportion of the joint has been lost. The use of total implants reconstructing the head and acetabulum has become a standard. Also, an individual design of plates adjacent to the bone is becoming an accepted norm. The developed procedures include the process of obtaining data using computed tomography, individual implant fitting and verification engineering analyses. The paper presents an example of an individual design process for a temporomandibular joint implant.

Keywords: temporomandibular joint, reconstruction, custom made implants

1.1. The temporomandibular joint

The temporomandibular joint (TMJ) consists of two bone elements, the mandibular fossa and the mandibular head. Both of these elements are separated from each other by the intra-articular cartilage that divides the joint into the so-called two floors surrounded by an articular capsule reinforced with ligaments [1].

Temporomandibular joints are functionally and anatomically linked with each other, thanks to mandibular bones articular heads. Therefore, they are different from the rest of the joints in the human body. The main stimuli that affect suction include pressure on the articular surfaces by the disc and mandibular bone heads, contractions and changes in the length of muscle fibers, and muscle tension [1, 2, 3]. Pathogenic factors, and more precisely their effect on the temporomandibular joint, may cause inflammatory processes not only in adulthood, but also in the child's development. Inflammation can affect individual parts of the joint, the entire joint, or the joint and the muscular apparatus. The harmful effect of pathogens may disrupt the proper development of temporomandibular joints [4].

Implants are more and more often used to restore the proper functions in the temporomandibular joint. Quite a large percentage of patients qualified for implantation have distorted anatomy of the temporomandibular joint due to previous surgical interventions or due to pathological conditions of the joint. Such situations additionally increase the difficulty of performing a stable reconstruction with the use of standard implant components. Contraindications for performing surgical procedures with the use of a temporomandibular joint implant are chronic infection in the site after surgery and hypersensitivity related to the material from which the implant was made. The most commonly used biomaterials for implants are titanium and cobalt-chrome alloys for the condyle, and high molecular weight polyethylene for the acetabular insert [5, 6].

Due to the development of craniofacial radiology, prostheses of the temporomandibular joint are more and more often adapted to the patient's anatomy, which allows for a more precise adjustment of the implant to the mandibular bone and better adaptation of the implants. Implants of this type are performed with the aid of computer support, based on radiographic images of the patient made with the use of computed tomography [7]. Additionally, individual prostheses of the temporomandibular joint enable better load transfer, reduction of micromovements, as well as better adjustment and positioning with screws. At the same time, they allow to shorten the time needed to perform the surgery [8, 9].

1.2. Analysis of the existing solutions of the temporomandibular joint implant

Surgical procedures of the temporomandibular joint with the use of joint implants are used only in cases where traditional procedures are insufficient to improve its functioning.

The main advantage of using temporomandibular joint implants is immediate restoration of joint functions without the need for jaw blockage after surgery [10]. Additionally, alloplastic reconstruction makes it possible to start physiotherapy immediately after implantation and shorten the duration of the operation [6].

Temporomandibular joint implants faithfully reflect the structure of the natural joint, they consist of a concave acetabulum attached to the skull and a convex head with a plate attached to the mandibular branch. Among the implants of the temporomandibular joint, one can distinguish two, three and four-piece constructions. Most ompanies offer implants in several sizes with the possibility of individual adjustment.

An example of a two-piece implant is the ZIMMER BIOMET implant (Fig. 1.1). It is made of a cobalt chrome plate with a head and a polyethylene acetabular cup. This type of solution allows to reduce production costs and limit the introduction of metal elements into the human body [11].

An example of a three-piece design is the OrthoTiN implant (Fig. 1.2). In this case, the cup is made of two elements: a plate made of titanium alloy and a polyethylene insert, while the head implant is a monolith [12].

a) b)

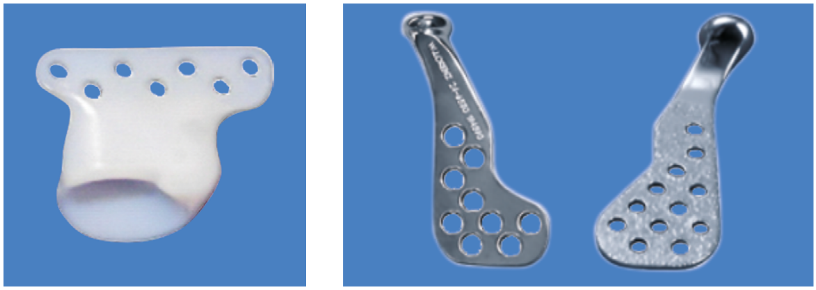

FIGURE 1.1. The implant cup (a) and plate (b) by ZIMMER BIOMET [11]

a) b)

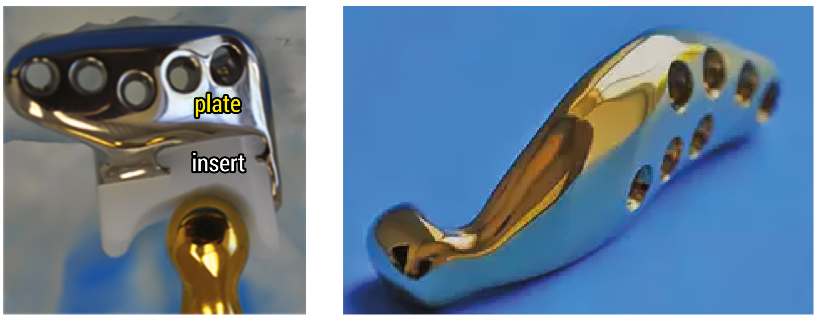

FIGURE 1.2. OrthoTiN implant cup (a) and plate (b)[12]

An example of a four-piece implant is the design of the PRÓTESE DE ATM CUSTOMIZADA company (Fig. 1.3). It is a type of blocked implant of the temporomandibular joint intended for total joint arthroplasty. The ATM implant plate is made of Ti6Al4V titanium alloy, while the plate head is made of CoCrMo alloy. The implant cup is, as before, two-part and consists of a plate made of Ti6Al4V alloy and a polyethylene insert [13].

a) b)

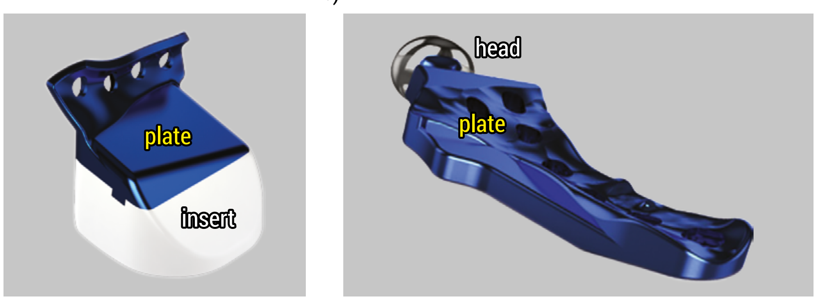

FIGURE 1.3. The implant cup (a) and plate (b) by Próteses Customizadas De ATM [13]

1.3. Designing an individual implant of the temporomandibular joint

Designing patient-specific implants is particularly applicable to irregularly shaped bones (skull, pelvis).

When designing an individual implant of the temporomandibular joint, the following design assumptions were adopted:

- individual adjustment of the temporomandibular joint implant,
- restoration of the basic functions of the temporomandibular joint
- the use of fixing screws intended for the cortical bone,
- the use of biocompatible materials used to manufacture implants for the temporomandibular joint, while maintaining the best possible structural strength parameters.

Designing an implant specially adapted to a given patient begins with radiological examinations using computed tomography (CT). It is thanks to this radiological examination that at a later stage it is possible to create a three-dimensional model of the jaw and skull (Fig. 1.4). Currently, the methodology of human tissue segmentation based on computed tomography is widely known, and more and more software can be found on the market. [14,15]. The presented models were made with the use of free and open source 3D Slicer image computing platform.

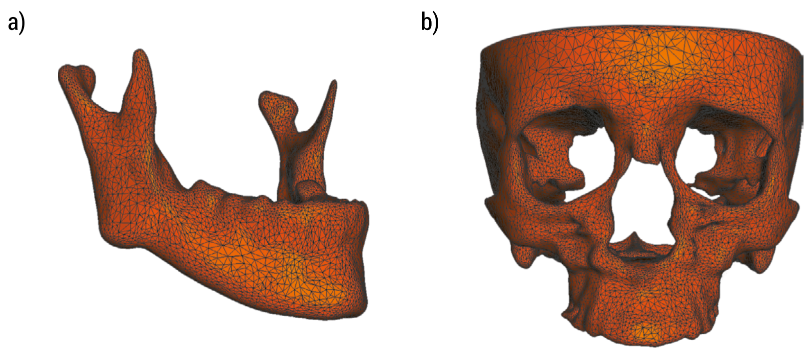

FIGURE 1.4. Model of (a) the jaw and (b) the skull

In the next step, based on the obtained geometry, an implant model is created that reflects the individual characteristics of the patient. The models were made in the CAD3D SolidWorks engineering software. The anatomical, individually fitted contact surface of the implant with the bone was obtained using Boolean operations. The received implant model reflects the individual characteristics of the patient's surface bone. Fig. 1.5a shows the process of creating the shape of the mandibular branch implant, Fig. 1.5b – the fitting of the implant to the bone and, eventually, Fig. 1.5c – the resulting implants with individually reconstructed surfaces.

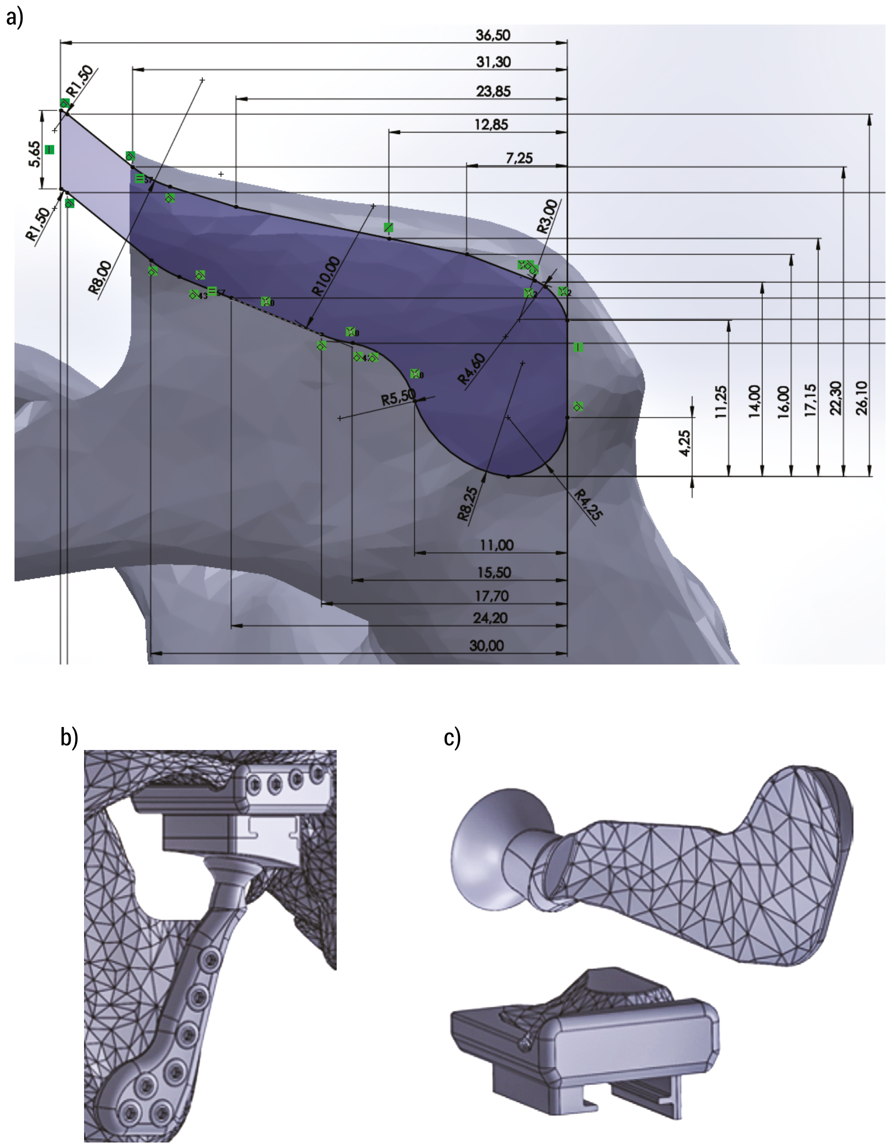

FIGURE 1.5. **Designing an individual implant of the temporomandibular joint: (a) determining the boundary of the implant, (b) fitting the implant, (c) implant with the mapped geometry**

After designing the implant, a very important element of the entire process is its validation, during which the geometry of the implant and the method of its mounting are analyzed. Validation is carried out through strength tests with the use of finite element analysis [16, 17, 18].

The paper presents an example of a strength analysis of a mandibular branch implant. A force loading the plate model of 200 N was assumed, all holes were used to stabilize the implant (Fig. 1.6). The plate material was made of Ti6Al4V alloy. The analysis was carried out for 3 variants of the force, which was set at an angle of 5°, 10° and 15° in order to simulate different angles of the mandible.

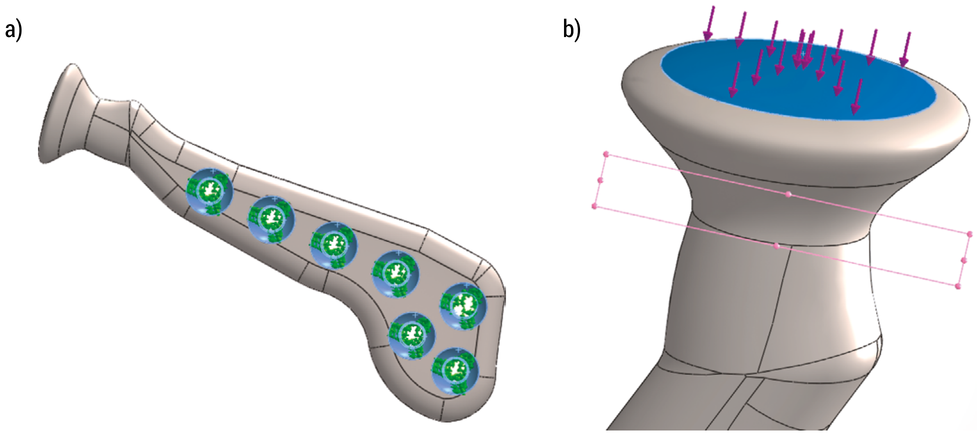

FIGURE 1.6. Boundary conditions for the implant model of the condylar plate

The figures below (Fig. 1.7a,b,c) show the result of stress simulation for the implant of the condylar plate of the temporomandibular joint. As a result of the analysis, the readings of the stress distribution according to the Huber Mises hypothesis were obtained. As expected, the concentration of stresses can be observed in the narrowing of the implant and in the area of the first fastening hole. The maximum value of stresses increases with the angle of the force (mandible opening) and is for the angle of 5° – 62.652 MPa, 10° – 89.425 MPa and 136.276 MPa for 15°. It corresponds to the increase in the value of the moment resulting from the change of the direction of the applied force. The yield point of 830 MPa for the material used was not exceeded in any of the cases.

FIGURE 1.7. Readings of the resulting stresses for the condylar plate in the test with the force loading the implant at an angle of (a) 5°

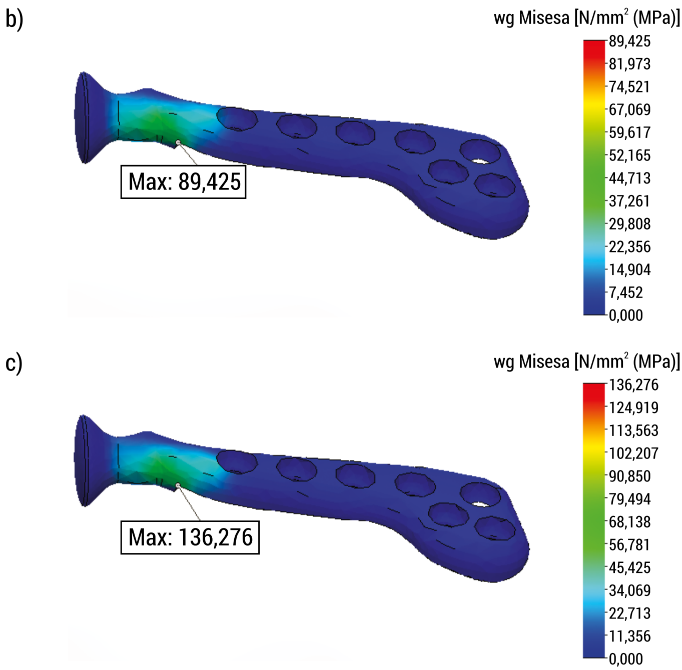

FIGURE 1.7. Readings of the resulting stresses for the condylar plate in the test with the force loading the implant at an angle of (b) 10°, (c) 15°

1.4. Conclusions

The temporomandibular joint plays an important role in the functioning of not only the masticatory system but the entire body. It accounts for the chewing and breathing processes. Therefore, any disturbances within it have serious consequences. In reconstructive surgery, implants are increasingly used to reconstruct the diseased joint. The development of computer technology supports the planning of operations and manufacturing technology, which makes it possible to manufacture "custom-made" implants precisely matched to the irregular geometry of the skull. In the case of such constructions, it is important to perform verification calculations using the finite element method.

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