BIOMECHANICAL ASPECTS OF CHEWING EFFORT DISTRIBUTION AFTER THE MAXILLARY SINUSOTOMY

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Abstract: As a result of a classical Coldwell-Luc operation on the perirhinal maxillary sinus, the trepanation bone defect stays in the anterior wall of the sinus. In this case, soft tissues of cheek and cicatricial tissue are growing into the sinus, and it causes the relapse of inflammation and the development of pathologic symptom-complex. To eliminate this defect, different methods of its filling with transplants and implants are used. When the implant fixing is insufficiently rigid, the implant rejection occurs due to deformations under cyclic chewing loads. Consequently it is necessary to carry out the biomechanical study of maxillary bone and the mathematical substantiation of need to close the trepanation defect.

Key words: maxillary sinusotomy, efforts of masticatory muscles, trepanation defect

Introduction. Surgery of the maxillary sinus

The prevailing treatment in cases of maxillary sinus diseases is a surgical intervention. Present time both intranasal operations with application of optical devices and extranasal surgical operations are in use. The external operative access to maxillary sinus or antrum of Highmore (Fig. 1) allows carrying out the sanative treatment of the whole sinus, removing foreign objects and start points of osteomyelitis.

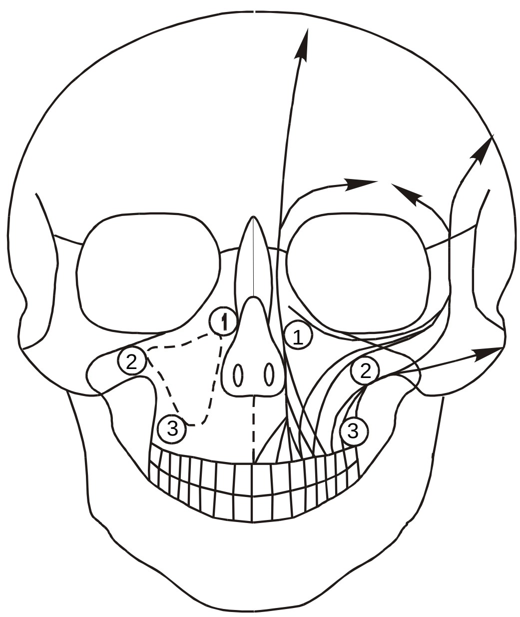

Fig.1. The chewing load transfer from teeth to the maxilla (the dotted line indicates the boundary of the maxillary sinus): 1 – frontonasal counterfort, 2-zigomatic counterfort, 3-pterygopalatine counterfort.

This method is employed in medical treatment of proliferative and complicated forms of maxillary sinusitis. The main concept of any operative intervention into perirhinal sinuses is to establish the stable communication with the nasal cavity, in order to maintain free drainage of secretion and adequate cavity ventilation. As a result, after the operation the conditions in the sinus are nearly physiologic, and it allows eliminating the development of inflammation. The most commonly employed method of extranasal surgical intervention to maxillary sinus is the Caldwell–Luc operation. The surgeons have been operated in this way for more than a century, it consists in resection both anterior and nasal osteal sinus walls, with completely or partly removal of mucous membrane [1-5].

The results and consequences of maxillary sinusotomy

Postoperative relapses of suppurative and polypous processes in maxillary sinus take place in 5 % to 36 % of cases [1,3]. In the distant postoperative period, some patients are subject to pathologic symptom-complex: painful sensations in infraorbital region, disorders in teeth and facies sensitivity, neuropathy of trigeminal nerve and other symptoms [1-5]. The relapse of suppurative process in maxillary sinus and development of postoperative symptom-complex are regarded to be a consequence of cicatricial process in the region of maxillary sinus trepanation defect. Through this osteal defect the soft cheek tissues and the cicatricial tissue are growing into the sinus. It causes formation the cavities without drainage and suppurative foci in the sinus, and encourages obliteration of anastomosis [1-5]. To prevent the relapse of pathologic process and postoperative symptom-complex, a number of surgeons offered methods of covering the trepanation osteal defect of the maxillary sinus anterior wall by auto- and allotransplants and different implants [2,4,5]. Methods of osteoplastic operations with application of surgical ultrasound [1] and method of obliteration of the maxillary sinus by adipose and muscular tissue [3] were proposed. Implant or transplant covering the bony defect is a barrier to growing of cicatricial tissue into the sinus, and facilitates the complete recovering of all the functions of perirhinal sinus. At the Department of Otolaryngology of Perm State Medical Academy the covering the postoperative defect in the anterior wall of the sinus by carbon-carbonic implant is a routine practice. The implant is fixed in the trepanation defect by osteosuture with carbonic threat.

In the nearest postoperative period, two patients showed the implant rejection without accompanying inflammation. The cause of implant incompetence, in our opinion, consists in its insufficiently rigid fixing and in possibility of implant shifting under chewing cyclic loads.

The significance of the osteal structures injuries

The maxilla is a stationary twin bone. Maxillary sinus located in the maxilla is a pneumatic cavity. Walls of the sinus are thin osteal laminae, and the thinnest wall is the anterior one. The maxilla is exposed to cyclic loads and deformations under chewing. The chewing load transfers by maxillary counterforts to the squama of cerebral cranium [6,7] (Fig.1).

The main part of the load is transferred by three ways: 1) from the canine tooth to the frontal process of the maxilla through the frontonasal counterfort, 2) from the first molar tooth to the zygomatic bone through the zygomatic counterfort, and 3) from the premolars to the pterygoid processes through the pterigopalatine counterfort. In the bone structure of the cranium the counterforts play the role of stiffening ribs. The load is developed by the masticatoty muscles and transfers through the regions of their fixation to the mandible and the maxilla.

Under the operations on the antrum of Highmore, beside of bone destruction in the region of fossa canina, both frontonasal and zygomatic counterforts are damaged. Under the most commonly used Caldwell-Luc operation, the frontonasal counterfort is partly injured, whereas under the Denker operation it is completely damaged. The chewing loads from the anterior teeth and the canine tooth after the operation are transferred by the different way. It overloads undamaged bone structures and obstructs usual food chewing process. The removal of the part of the bone in the region of fossa canina leads to its strength decrease and reduction of its possibility to endure great chewing loads. In this case, the whole maxillary biomechanical structure is undoubtedly changed, and it inevitably leads to disturbance of bone functions.

The objective of the investigation

To estimate the maxilla strength after the maxillary sinusotomy, we need an information on the stresses and strains in it under food chewing. For this purpose we have to know not only the total chewing load but also the forces in each masticatory muscle. The shape of the bone defect after the surgical intervention is known, and the subject of our interest is the form of carbon-carbonic implant which would allow installing it with a tightness appropriate for the secure fixing under cyclic chewing loads.

The forces developed by the human masticatory muscles

The system of the human masticatory muscles consists of the chewer or masseter, the temporalis, the internal and external pterygoid, and the digastric. They exert the forces $\mathbf{F_m}$, $\mathbf{F_t}$, $\mathbf{F_i}$, $\mathbf{F_e}$, $\mathbf{F_o}$, respectively [8], which are shown in Fig. 2. The vector $\mathbf{R}$ designates the reaction force at the temporomandibular joint, and $\mathbf{F}$ denotes the occlusal load. The origin is chosen at the centre of the condyle projection on the cranium and mandible plane of symmetry.

In each muscle except the temporalis, the muscle fibers are parallel, consequently the direction of its force vector can be determined as a direction from the point of the origin at the mandible to the point of insertion at the maxilla. The fibers of the temporalis are widely radiated in the temporal region, therefore according to the paper [8], the force vector $\mathbf{F_t}$ representing its action on the mandible is the vector sum of all the forces exerted by the

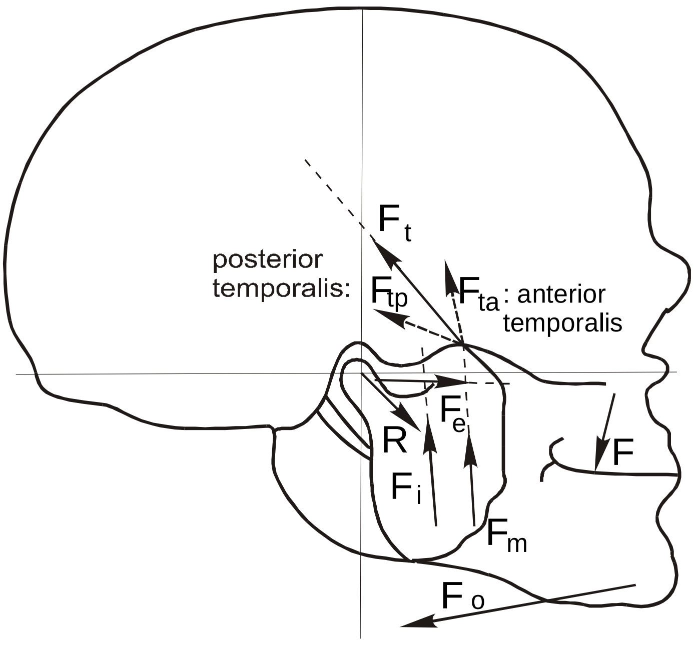

Fig. 2. The forces applied to the mandible from the masticatory muscles.

individual muscle fibers.

The application points of forces developed by five masticatory muscles and their directions as well as the chewing load are assumed to be known, therefore the static equilibrium of the mandible may be considered by setting up three equilibrium equations for the case of planar system of forces. The unknowns are the magnitudes of five muscular forces, and the magnitude and direction of reaction force at the temporomandibular joint. This problem is statically indeterminate. To find the muscular efforts it is necessary to assume the muscular activation during chewing occurs according to some mechanism that exists in the central nervous system.

The experimental information on the actual arrangement of the forces exerted by maxillary muscles may be taken by electromyography (EMG). In the paper by van Eijden et al. [9], it is shown that each individual direction of the chewing load corresponds to the unique manner of muscular activation which does not depend on the magnitude of the chewing force. This force is always a result of total action of the masticatory muscles but the criterions are unknown by which the central nervous system activates the appropriate combination of muscles.

Prium et al. [10] measured by EMG the activation of muscular groups during the chewing process, and used the results in a mathematical model in order to determine the muscular forces. In comparison with the paper [8], some simplifications were assumed (the masseter and the internal pterygoid forces were replaced by single force vector, and the lateral pterygoid was considered to be parallel to the occlusal plane), and the muscular forces were obtained from measured EMG values and muscular cross-sectional areas.

Barbenel in the paper [11] used linear programming by adding to the static equations the criterion of minimal reaction force at the temporomandibular joint or minimal sum of forces acting on the mandible. In his model, four forces exerted by the masseter, the temporalis, the medial and lateral pterygoid muscles were included. The calculations showed solely the masseter takes part in production of the chewing force, and the conclusion was made that these minimizing principles did not have any substantial significance.

Kang et al. [8] complemented the static equations by the principle of minimizing the largest muscle effort, as suggested by An et al. [12]. There were used the data by Grant [13] and Prium et al. [10] on the relative area of muscular cross section, and the simplex algorithm in the minimization procedure.

The cross-sectional areas of the masticatory muscles and maximal muscular forces according to different authors are represented in Tab. 1 and Tab. 2.

Table 1. Physiological cross-sectional areas of muscles.

Muscle	Grant [13]		Pruim et al. [10]	
	cm^2	ratio	cm^2	ratio
Masseter	2.53	1.0	3.4	1.0
internal pterygoid	1.43	0.57	1.9	0.56
anterior temporalis	1.65	0.65	2.6	0.76
posterior temporalis	1.65	0.65	1.6	0.47
temporalis total	3.3	1.3	4.2	1.24
digastric			1.0	0.29
external pterygoid			2.1	0.62

Table 2. Maximum allowable muscle forces.

Muscle	Cross-sectional area of muscle (cm^2)	measured F^{max} (N) [10]	predicted F^{max} (N) [8]
masseter	3.4		408
medial pterygoid	1.9	640	228
anterior temporalis	2.6	362	312
posterior temporalis	1.6	198	192
temporalis total	3.9	526	468
digastric	1.0	115	120
lateral pterygoid	2.1	379	252

The next steps in biomechanical analysis must contain the determination of forces in masticatory muscles (this problem is statically indeterminate), the determination of stress and strain with and without implant and the solution of optimal problem.

Conclusions

1. The operation of maxillary sinusotomy changes the biomechanical structure of human maxilla and it leads to disturbance of the bone function. One of the ways of its recovering is filling the defect by a carbon-carbonic implant.
2. The efforts of the human masticatory muscles cyclically load the maxilla, and it is one of the causes of implant rejection.
3. In order to avoid this phenomenon it is necessary to solve appropriate problem of biomechanics and optimal design.

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БИОМЕХАНИЧЕСКИЕ АСПЕКТЫ ПРИ РАСПРЕДЕЛЕНИИ ЖЕВАТЕЛЬНЫХ УСИЛИЙ ПОСЛЕ ОПЕРАЦИИ ГАЙМОРОТОМИИ ВЕРХНЕЙ ЧЕЛЮСТИ ЧЕЛОВЕКА

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При классических оперативных вмешательствах на верхнечелюстной околоносовой пазухе по Coldwell – Luc остается трепанационный костный дефект в передней стенке пазухи. Мягкие ткани щеки и рубцовая ткань при наличии дефекта врастают в полость пазухи, что приводит к рецидиву воспаления и развитию патологического симптомокомплекса. Для ликвидации трепанационного дефекта применяются методы пломбирования дефекта трансплантатами и имплантатами. При недостаточно жесткой фиксации имплантата происходит его отторжение, вследствие деформаций при циклических жевательных нагрузках. Необходимо биомеханическое исследование верхнечелюстной кости и математическое обоснование необходимости закрытия трепанационного дефекта. Библ. 13.

Ключевые слова: гайморотомия, усилия жевательных мышц, трепанационный дефект

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