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STATUS OF THE MAXILLARY BONE AFTER COLDWELL – LUC OPERATION

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Abstract. It is known that a trepanation bone defect in the front wall of the sinus remains after Coldwell - Luc surgical operation in the maxillary sinus. Mild tissues of cheek and scarry tissue in the presence of defect grow into the cavity of the sinus that brings about the relapse of inflammation and development of pathological syndrome. Methods of filling a defect by transplants and implants are used for liquidation of trepanation defect. Under insufficiently hard fixation of implant its rejection takes place due to deformation under variable chewing loads. Therefore it is necessary to conduct the biomechanical study of the maxillary bone and mathematical substantiation of choice of sizes of trepanation defect and need of its closing. For this purpose Coldwell – Luc operation is considered and analysed its consequence for the maxillary bone both from medical and from biomechanical viewpoint with the help of solution of boundary-value problem of theory of elasticity.

Key words: surgical stomatology, maxillary sinusotomy, masticatory muscles, stress, finite element method

Introduction

To date Coldwell – Luc operation is the most effective and widespread method in clinical practice for surgical treatment of maxillary chronic sinusitis. This operation was proposed by American surgeon Coldwell in 1893 and French surgeon Luc described it independently in 1897 [1, 5, 7, 11, 13]. Many authors consider Coldwell – Luc operation as the very effective method. This method provides a way examining the maxillary sinus and extracting all pathologic tissues. This method facilitates drain and ventilation of the maxillary sinus after operation [1, 5, 7, 8, 9, 11, 13, 14, 15].

The strategy of Coldwell - Luc operation is as follows. The surgeon does a horizontal cut of mild tissues on transitional fold to the bone from the lateral incisor to the third molar. The flap together with the periosteum is shifted and drawn upward exposing the area of the canine fossa. In the centre of the canine fossa the surgeon produces trepanation by gouge or chisel increasing trepanation defect (practically it is a resection of the front wall of the maxillary sinus). Then it is necessary carefully to delete the whole mucous shell of the sinus and create artificial broad anastomosis in the inferior nasal passage. The Π – shaped flap is created from the lateral wall in the inferior nasal passage which is put on the bottom of the sinus. The sinus is carefully tamponed by gauze tampon [1,13].

Advantages of Coldwell – Luc operation of maxillary sinusotomy are the good maxillary sinus review and the better drain and ventilation than in endonasal operation. We can state with assurance that Coldwell – Luc operation withstood the test of time and it is used in the best otorhinolaryngological clinics in the world.

There are modifications of Coldwell - Luc operation where it is possible to save a mucous shell of the sinus, to reduce a trepanation defect to minimum. However the general principle of these and other operations is preserved: a resection of the front wall of the maxillary sinus for full elimination of pathological focus and creation of artificial anastomosis from the sinus to the nasal cavity [1, 5, 8, 14].

Bone defects of maxillary sinuses forming as a result of radical operations or after traumas, cause to a great extent drawing soft tissues and following adhesion with the back wall that leads to overgrowing anastomosis and increasing the relapses of disease [8, 9, 10, 11, 13, 14]. The germinated tissue can accrete with the medial wall of the sinus, creating by doing so many chambers or isolated cavities filled by pus. As this takes place some persons have sinuses divided into several cavities, many from them are filled by pathologic discharge and have no connections with the nasal cavity [5, 7, 8, 11, 14]. Such tissue often necrotizes and newly can promote a disease relapse [3, 5, 10, 11]. It is known that after operations in the sinus the fibrosis processes run that brings about reducing its volume [7, 9].

In turn a fibrous tissue formation creates in the sinus lumen the conditions for development of inflammatory processes in cavities of the operated sinus. Under classical Coldwell - Luc operation the vegetation of cheek mild tissues into the sinus takes place, vegetated tissues are covered by granulations [5, 7, 14].

After radical surgical interference in the maxillary sinus there is always a partial or subtotal its obliteration, filling by granulations, fibrous tissues and sometimes by a pus. As a result the pneumatic and resonant function are broken.

The pathological syndrome after Coldwell – Luc operation is a consequence of trauma of surrounding tissues and postoperative defect of the front wall of the sinus [14]. Approximately 20% patients after Coldwell - Luc operation of the maxillary sinusotomy have complaints of innervation breaking (sensitivity breaking, pains, prosthetics difficulties) [13, 14].

After radical Coldwell - Luc operation in the maxillary sinuses the teeth injuries are possible because of blood supply and innervation damage. Cases of pulp necrosis, loss of sensitivity, etc. are known [7, 14,15]. After radical operation in the maxillary antrum it is observed reduction of teeth electrosensitivity in the upper jaw up to its absence. The most sharp reduction of electrosensitivity is noted near the fourth, fifth and sixth teeth on the operated side which was not normalised during one year [2].

Modern principle of maxillary sinus surgery is as follows: the trepanation hole must be minimal but ensuring a good review of the sinus [7, 13]. In the last ten years osteoplastic operations are accomplished for the purpose of removal or reducing an area deformation and for reducing a frequency of relapses of disease. It preserves the aireness of the operated sinus. To do this would require autografts, allografts, implants, and sinuses obliteration [6, 7, 11, 13].

Aim of the research

Coldwell - Luc operation leads to considerable destroying the front wall of the maxillary sinus and counterforts of the upper jaw [15,16] that brings about the redistribution of chewing loads in the field of trepanation holes. Reduction of rigidity leads to increasing a mobility of the whole upper jaw that can give rise to pinch soft tissues, nerves and nervous endings. The strength of the maxillary bone diminishes due to a local stress concentration near the trepanation hole.

The aim of this research is determination of chewing loads in the maxillary bone when chewing and biting a food in the norm and in the presence of trepanation holes of different sizes.

We consider the face wall of the maxillary sinus damaged in Coldwell – Luc operation as a plate of variable thickness with the hole corresponding to the trepanation hole within the framework of linear theory of elasticity.

Mathematical model

Linear problem of theory of elasticity includes the equations:

1. Two-dimensional differential equations of equilibrium

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + X = 0, \tag{1}$$

$$\frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + Y = 0, \tag{2}$$

where vertical axis Oy is directed upwards, X, Y – components of body force, $X = 0$. If ρ - density of bone, then $Y = -\rho g$, where g -is acceleration of the free fall.

2. Two-dimensional Hooke's law - linear relation between components of stress and strain

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \frac{E}{1+\nu} \begin{bmatrix} \frac{1}{1-\nu} & \frac{1}{1-\nu} & 0 \\ \frac{1}{1-\nu} & \frac{1}{1-\nu} & 0 \\ 0 & 0 & \frac{1}{2} \end{bmatrix} \times \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}, \tag{3}$$

where E - Young's modulus, ν - Poisson's ratio.

3. Linearized geometric relations

$$\varepsilon_x = \frac{\partial u}{\partial x},\ \varepsilon_y = \frac{\partial v}{\partial y},\ \gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}. \tag{4}$$

Here u, v - components of displacement which are functions of coordinates x, y. Transverse deformation is defined as $\varepsilon_z = \frac{\nu(\sigma_x + \sigma_y)}{E}$, but transverse stress $\sigma_z = 0$.

Considered area presents itself part of the upper jaw which is projected on the plane parallel plane containing the trepanation hole (Fig.1). Problem (1)-(4) is solved numerically by the method of finite elements (computer programme Elast 2D).

Computer programme Elast 2D

Computer programme Elast 2D is based on the method of finite elements. It allows calculating stress and strain in problem of linear theory of elasticity. Knowing geometrical parameters of a structure, boundary conditions and mechanical properties of material we can calculate components of strain and stress at every point of the structure.

Beforehand we solved a test example for plate with hole using computer programme Elast 2D (Fig. 2). The prescribed boundary conditions are as follows:

$$v = 0,\ F_x = 0,\ \forall x \in S_1,$$

$$u = 0,\ F_y = 0,\ \forall x \in S_2,$$

$$F_x = 0,\ F_y = q,\ \forall x \in S_3,$$

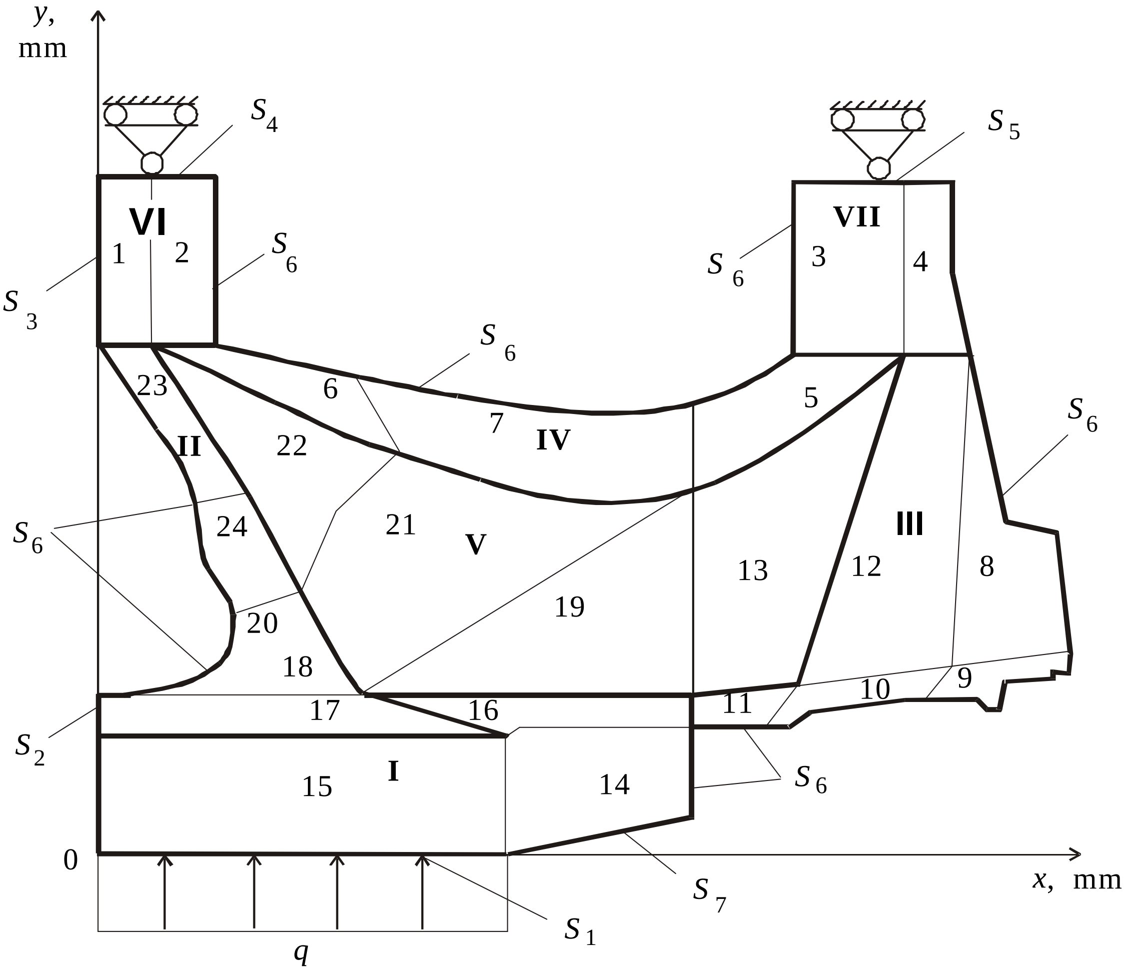

Fig.1. Diagram of considered structure.

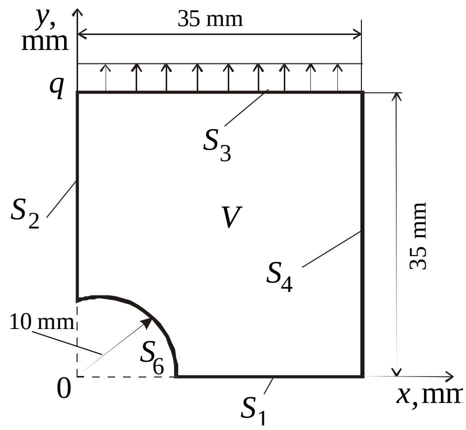

Fig. 2. Plate with hole. Properties and load: $E = 210000\ \text{MPa}$, $\nu = 0.25$, $q = 13\ \text{MPa}$.

Table 1. Mechanical properties of the maxillary bone.

№ sub-structure	Spongy material (%)	Compact material (%)	E (MPa)	ν
I	72	28	6320	0.3
II	1	99	19811	0.3
III	7	93	18660	0.3
IV	62	38	9020	0.3
V	0.2	99.8	19770	0.3
VI	2	98	19662	0.3
VII	0.6	99.4	19860	0.3

$$F_x = 0,\ F_y = 0,\ \forall x \in S_4 \cup S_5 .$$

We received distribution of components of normal stress σ_x, σ_y and shear stress τ_{xy} in the structure V. To check correctness of received results we considered analytical solution of problem of theory of elasticity for plate with hole [17]. Comparison of results of numerical solution with results of analytical solution allows us to draw the conclusion on sufficient accuracy of numerical solution.

Calculation of the stress-strain state of the upper jaw

After analysis of the test example we come to the conclusion that by means of computer programme Elast 2D it is possible to determine components of stress and strain for plates having different holes with different boundary conditions, variable thickness and parameters of material.

The determination of the stress-strain state of the maxillary bone when chewing a food in the absence of trepanation holes (Fig.1)

Given the boundary conditions on surfaces S_i ($i = 1, 2, ..., 7$), q - chewing load:

$$F_x = 0,\ F_y = q,\ \forall x \in S_1,$$
$$u = 0,\ F_y = 0,\ \forall x \in S_2 \cup S_3,$$
$$F_x = 0,\ F_y = 0,\ \forall x \in S_6 \cup S_7,$$
$$v = 0,\ F_x = 0,\ \forall x \in S_4 \cup S_5 .$$

Mechanical properties of bone:

1) compact bone $E_c = 20000$ MPa , $\nu_c = 0.32$;

2) spongy bone $E_s = 1000$ MPa , $\nu_s = 0.28$ [18].

Depending on percentage content of compact and spongy material in bone the considered structure is divided into seven substructures (Roman numerals in Fig. 3). Modulus of elasticity of every substructure is determined from the formula of mixture through percentage relation of thickness of compact and spongy bone.

$$E = \frac{E_c t_c + E_s t_s}{t_c + t_s} .$$

The results are presented in Table 1.

Depending on thickness of bone [19] the considered structure is divided into 24 subregions (Arabic numerals in Fig. 3). The modulus of elasticity for each of 24 subregions is multiplied by the thickness of the bone in this subregion (Table 2).

Analogous problems were solved when biting off a food and in the presence of trepanation holes of different sizes. Trepanation hole in bones was taken into account by the setting practically zero modulus of elasticity.

Results of numeral analysis of the stress-strain state of the maxillary bone

From variety of received results of calculations the vertical stress in healthy and damaged bone are presented in Fig. 4, 5 6. Different sizes of trepanation hole of the maxillary bone are considered.

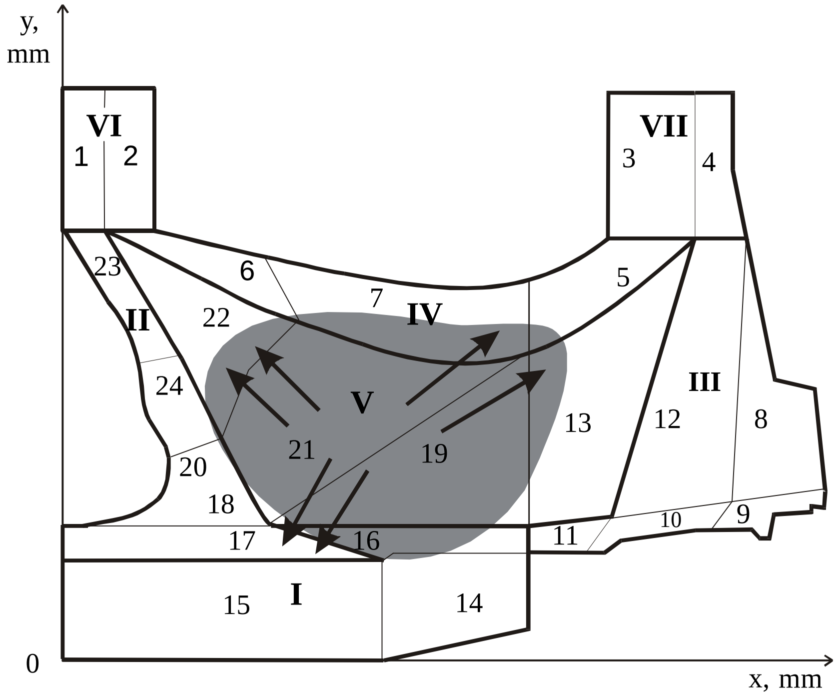

Fig.3. Projection of the maxillary sinus on plane of the maxillary bone.
Arrows show increased thickness of bone.

Table 2. Thickness, mean thickness and effective modulus of elasticity.

№ of subregion	d (мм)	d_m (мм)	$E_{eff}/10$ (MPa)
1	2.7	2.7	5297.4
2	2.7	2.7	5297.4
3	4.79 – 6.35	5.57	11323.6
4	5.01 – 6.23	5.62	11164.7
5	4.79 – 6.35	5.57	5024
6	4.79 – 6.35	5.57	5024
7	4.79 – 6.35	5.57	5024
8	5.01 – 6.23	5.62	10492.5
9	2.9 – 3.4	3.15	5881.05
10	2.9 – 3.4	3.15	5881.05
11	3.8 – 4.7	4.25	7934.75
12	5.01 – 6.23	5.62	10492.5
13	0.19 – 0.27	0.23	454.7
14	10.43 – 13.2	12.1	7647.2
15	7.2 – 11.25	9.2	5814.4
16	10.4 – 15.3	10.86	6863.5
17	10.2 – 12.3	11.25	7110
18	2.5 – 3.0	2.75	5448
19	0.19 – 0.27	0.23	454.7
20	1.5 – 1.9	1.7	3367.9
21	0.21 – 0.33	0.27	533.8
22	1.2 – 1.7	1.49	2945.7
23	1.11 – 1.58	1.35	2674.5
24	1.5 – 1.9	1.7	3367.9

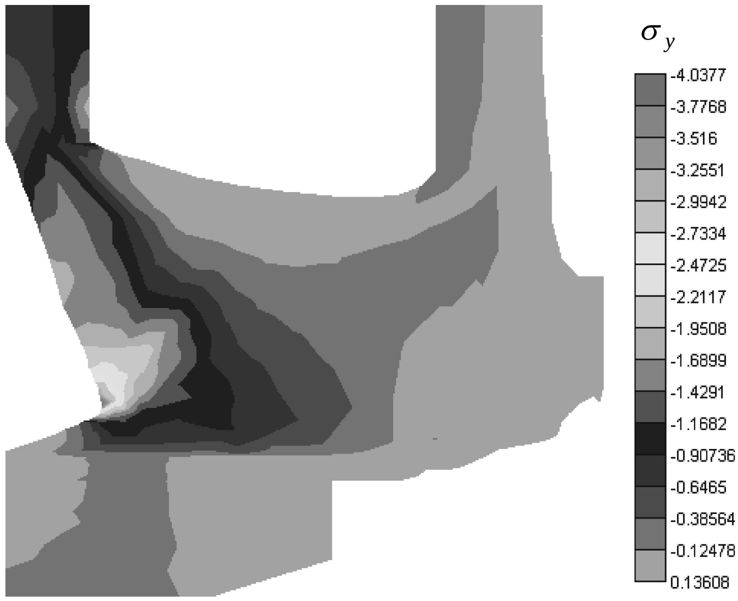

Fig.4. Vertical stress in healthy maxillary bone.

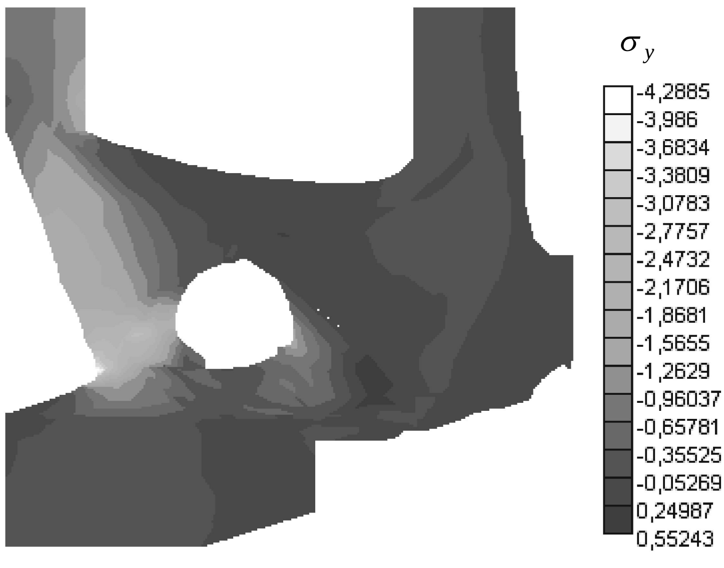

Fig.5. Vertical stress in the maxillary bone with small trepanation hole.

Analysis of results of calculations

1. Stress in healthy maxillary bone when biting and chewing a food reaches 40 MPa, strain reaches value $8 \cdot 10^{-3}$, these results coincide with the experiment [20].
2. Under loading compressive, tensile and shear strains take place (ε_x, ε_y, $\varepsilon_z, \gamma_{xy}$). Therewith shear strain is greater when biting off and reaches value $4.5 \cdot 10^{-3}$.

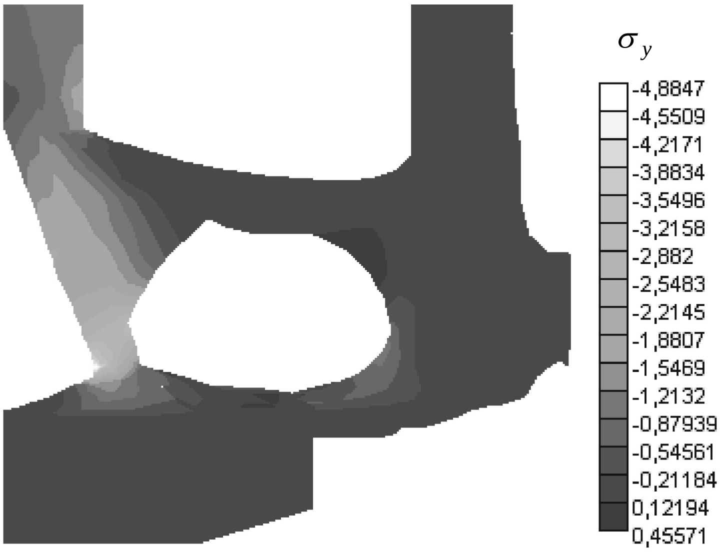

Fig.6. Vertical stress in the maxillary bone with large trepanation hole.

3. Stresses in the structure are basically compressive, but both when biting and chewing the stresses are tensile in the orbital margin and in the field of the process of the zygomatic bone.
4. Stress from chewing load is distributed on counterforts, when biting mainly on frontnasal counterfort, when chewing - sufficiently uniform on frontnasal and zygomatic counterforts.
5. When biting this stress localises in the field of alveolar and zygomatic processes and when chewing in the field of the 1th, the 2th, the 3th teeth. In the field of the zigomatic process tensile vertical stress reaches value up to 5 % maximal compressive stress.
6. With the availability of large trepanation hole all components of stress increase approximately of 25-30 %. It is connected with the redistribution of load on counterforts.
7. Under the small trepanation hole in the process of biting the vertical stress σ_y decreases in contrast with the large hole, but remains more than in healthy jaws. Normal stress σ_x and shear stress τ_{xy} increase of 10 % in the comparison with the large defect. This is connected with the fact that load when biting with the large hole transfers mainly through frontonasal counterfort but under the small hole begins "to work" the front wall of the maxillary sinus.
8. When chewing under the small front wall trepanation defect shear stress decreases in contrast to the large hole, maximal stress σ_y increases and moves from frontonasal to zygomatic counterfort. Stress σ_x changes insignificantly as diameter of hole increases.
9. Under small hole the shear stress increases on the boundary of hole when biting in contrast with large hole of 10 % approximately, stress σ_y is halved and stress σ_x is practically constant.
10. When chewing stress σ_x practically does not depend on value of hole, maximal σ_y insignificantly increases under the small hole in contrast with large one and localises near one margin of hole instead two margins. Stress τ_{xy} under the small hole is many fewer than under large one.

Conclusions

1. Trepanation hole enlarges all components of stress that is stipulated by excluding from work the front wall of the maxillary sinus in part or completely.
2. In the presence of hole the maximal value of shear stress and strain in direction of the chewing load turns out to be on the boundary of trepanation defect.
3. In the process of mechanical treatment of a food (biting and chewing) significant change of the stress-strain state takes place, moreover presence of defect considerably enlarges this effect.
4. The stress-strain state under mechanical treatment of a food with reducing the size of trepanation hole becomes more uniform.
5. Presence of trepanation hole in the front wall of the maxillary sinus, regardless of size, does the stress-strain state of the maxillary bone more hard, it changes physiological conditions of organ functioning.

References

1. БЕРНАДСКИЙ Ю.И., ЗАСЛАВСКИЙ Н.И. **Одонтогенные гаймориты.** Москва, Медицина, 1968 (in Russian).
2. МАРТФЕЛЬ И.Я. Электровозбудимость зубов при патологических процессах в верхнечелюстной пазухе. **Сборник научных трудов аспирантов и ординаторов: Московский медицинский стоматологический институт.** Москва, 141 – 142, 1971 (in Russian).
3. МИШЕНЬКИН Н.В. **Остеопластическая функциональная хирургия параназальных синуситов.** Омск, 1977 (in Russian).
4. НИКОЛАЕВ Р.М. Об использовании титановых сеток с биоситаллом для закрытия костных дефектов передних стенок верхнечелюстных и лобных пазух. **Российская ринология**, 2: 73, 1998 (in Russian).
5. ПАЛЬЧУН В.Т., УСТЬЯНОВ Ю.А., ДМИТРИЕВ Н.С. **Параназальные синуситы.** Москва, Медицина, 1982 (in Russian).
6. ПЛУЖНИКОВ М.С., КОССОВОЙ А.Л., МЕРКУЛОВ В.Г. Диагностика послеоперационных изменений в лобных и верхнечелюстных пазухах. **Вестник оториноларингологии**, 3: 22 – 25, 1992 (in Russian).
7. РЯБОВА М.Я., МЕРКУЛОВА В.Г. Болезни оперированной пазухи: диагностика и лечение. **Российская ринология**, 2: 61 – 62, 1996 (in Russian).
8. СИВАЧ В.А. Пластическая хирургия стенок верхнечелюстной пазухи. **Журнал ушных, носовых и горловых болезней**, 2: 85 – 89, 1990 (in Russian).
9. ЧУМАКОВ Ф.И. История хирургических вмешательств на верхнечелюстной пазухе. **Вестник оториноларингологии**, 5: 59 – 60,1997 (in Russian).
10. BUCHER J. BESCHWERDEN. Endoscopische und Radiologische Spatbefunde bei Patienten mit Racaloperierten Kieferhohlen. **Inaugural Dissertation zur Erlangung des Grades eines Doktor der Zahnheilkunde.** Giessen, 1984 (in German).
11. DRAF W. Der Gesichtsschmerz nach Coldwell - Luc - Operation. Prophylaxe und Therapie. **Laryngol Rhinol Otol**, 59 (5): 308 – 311, 1980 (in German).
12. OEKEN F., GORISCH I., DIETRICH A., HEMPEL E. Spatfolgen nach Coldwell - Luc - Operation bei der chronischen Kieferhohlenentzundung. **HNO - Praxis**, 10(1): 41 – 44, 1985 (in German).
13. PAAVOLAINEN M., PAAVOLAINEN R., TARKKANEN J. Influence of Coldwell - Luc Operation on Developing Permanent Teeth. **Laryngoscope**, 87, 4(1): 613 – 620, 1977.
14. Von WTSTERNHAGEN B. Die operative Kieferhohlensaierungien Routiweeingriff. **HNO - Praxis**, 31(5): 158 – 160, 1985 (in German).
15. SELYANINOV A.A., YELOVIKOV A.M. Biomechanical aspects of chewing effort distribution after the maxillary sinusotomy. **Russian Journal of Biomechanics**, 3(4): 62 – 67, 1999.
16. СЕЛЯНИНОВ А.А., ЕЛОВИКОВ А.М. К вопросу о состоянии костей верхней челюсти при гайморотомии. Тезисы доклада VII Всероссийского съезда по теоретической и прикладной механике. Пермь, 23-29 августа 2001 г., Екатеринбург, УрО РАН, 245-246, 2001 (in Russian).
17. ТИМОШЕНКО С.П., ГУДЬЕР Д. **Теория упругости.** Москва, 1979 (in Russian).
18. КНЕТС И. **Разрушение твердых биологических тканей.** Москва, 1986 (in Russian).
19. БУСЫГИН А.Т. **Строение челюстных костей.** Ташкент, 1962 (in Russian).

20. СЕМЕННИКОВ В.И., ХАУСТОВ Е.М. Характер распределения функционального напряжения в верхней челюсти. **Стоматология**, 1: 3 – 4, 1994 (in Russian).

СОСТОЯНИЕ ВЕРХНЕЧЕЛЮСТНОЙ КОСТИ ЧЕЛОВЕКА ПОСЛЕ ГАЙМОРОТОМИИ ПО COLDWELL- LUC

А.А. Селянинов, А.М. Еловиков, Н.Н. Фурина (Пермь, Россия)

При 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 переменных жевательных нагрузках. Необходимо биомеханическое исследование верхнечелюстной кости и математическое обоснование выбора размеров трепанационного дефекта и необходимости его закрытия. С этой целью рассматривается гайморотомия и ее последствия для верхнечелюстной кости как с медицинской, так с биомеханической точек зрения на основе решения краевой задачи теории упругости. Библ. 20.

Ключевые слова: хирургическая стоматология, гайморотомия, жевательная нагрузка, напряжения

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