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JUSTIFICATION OF THE BIOMECHANICAL MODEL OF EQUIVALENT STRESSES IN THE ALVEOLARY PROCESS AND DENTAL LUXATORS ANGLE INCLINATION DURING TOOTH EXTRACTION

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Relevance

The extraction of teeth remains the most prevalent surgical intervention to date, with lower third molars constituting the majority of these procedures. The positioning, specifically the angulation, of the lower third molar relative to the dental arch significantly influences the extraction technique [1; 2]. The removal of mesially inclined, impacted lower third molars continues to pose a complex challenge in dental surgery due to their frequent impaction, dystopia, and intricate topographic relationship with anatomical structures, particularly the inferior alveolar nerve. These factors considerably complicate the procedure, increasing the risk of trauma, prolonging the postoperative recovery period, and leading to complications such as fractures of the mandibular alveolar process, damage to nerve endings, and the development of infectious complications [3-6]. According to statistical data, more than 52% of mesially inclined lower third molars exhibit partial or complete impaction, underscoring the necessity for optimizing extraction methods [7; 8].

Postoperative and intraoperative complications following the extraction of mesially inclined lower third molars occur in 4-30% of cases, depending on the surgical technique, the surgeon's manual skills, the depth of impaction of the lower third molar, and the anatomical and physiological characteristics of the patient [9; 10]. In the routine practice of oral surgeons, the most frequently encountered complications include alveolar osteitis (5-15 %), fractures of the alveolar process (1-5 %), injuries to the inferior alveolar nerve (0.4-8 %), and infectious processes in the postoperative site (10-12 %). Additionally, patients often report severe pain in the extraction area, swelling, and trismus, which contribute to patient discomfort and negatively impact their quality of life [11-14].

Traditional methods for the extraction of mesially inclined lower impacted third molars are primarily based on the manual techniques of the surgeon, which can lead to variability in outcomes depending on the locus morbi, the overall somatic condition of the patient, and the experience of the practitioner [9; 15; 16].

Our research is focused on the integration of biomechanical analysis and the development of a mathematical model into the practice of oral surgeons. This approach holds the potential to enhance the quality of surgical planning for the extraction of impacted mesially inclined lower third molars, while minimizing tissue trauma.

This study is aimed at a more detailed investigation into the impact of biomechanical analysis during the surgical extraction of impacted lower third molars. By comparing techniques that utilize biomechanical analysis with standard protocols, it is possible to objectively evaluate their effectiveness in reducing trauma to soft and hard tissues, as well as in minimizing the occurrence of intra- and postoperative complications [17; 18].

Materials and methods of the study

The study was conducted at the Municipal Enterprise "Poltava Regional Dental Center – Dental Clinical Polyclinic" under the Poltava Regional Council, located in Poltava, Ukraine. A cross-sectional study was carried out involving 60 patients aged 18 to 35 years who underwent the extraction of mesially inclined impacted lower third molars between 2023 and 2024. Exclusion criteria included the presence of decompensated chronic diseases, psychiatric disorders, periodontal tissue diseases (generalized periodontitis in the acute stage), pregnancy, and unwillingness to participate in the study.

At the outset of the study, all participants were informed about the objectives, methods, protocols, and potential implications of the planned research, followed by the signing of a written informed consent form. The conducted research adhered to the principles of the Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects and was approved by the Bioethics Committee of Poltava State Medical University (Protocol No. 235 dated November 26, 2024) [19].

The patients were divided into two groups: the main group (30 individuals), where treatment was conducted according to a protocol incorporating biomechanical analysis and the creation of a mathematical model, and the control group (30 individuals), where the standard protocol for atypical tooth extraction was applied.

The biomechanical analysis and mathematical model were developed using the FEMAP 10.2.0 software. This method enables the optimization of dental luxators, reducing the load on the alveolar bone and periodontium. This contributes to minimizing postoperative complications, shortening recovery time, and enhancing the standardization of surgical techniques.

During the biomechanical studies, the focus was placed on analyzing the distribution of pressure on the alveolar bone and determining the optimal angle of inclination and position of the dental luxator during the extraction of impacted teeth. It was established that using the luxator at an angle of up to 25° from the horizontal plane significantly reduces the risk of bone tissue fractures. However, the question of clinical validation of these theoretical findings remains relevant.

Considering that the dental arch is located on the cantilevered, unanchored portion of the mandible and that the nearest support for bearing the load from the working part of the elevator can be considered the attachment site of the temporal and masseter muscles, it is rational to position the fulcrum of the elevator's working part at the apex of the alveolar process, as distally as possible (as close as feasible to the angle of the mandible). This approach aims to reduce the bending moment in the alveolar process. Consequently, the position of the elevator in the horizontal plane is determined by the anatomical feasibility of positioning the elevator handle closer to the mandibular ramus and is defined by the angle α between the projection of the elevator's working part onto the horizontal plane and the transverse axis (the line of intersection between the frontal and horizontal planes) (Fig. 1).

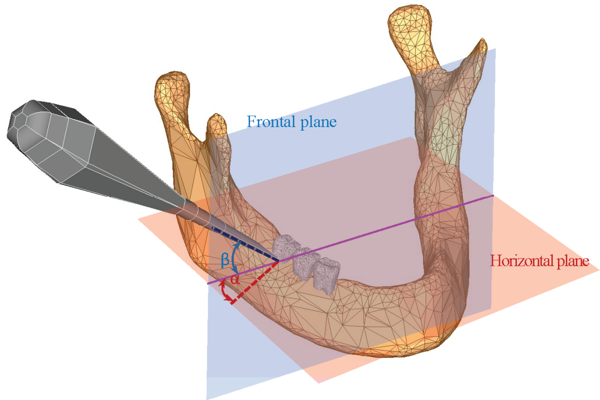

Figure 1. Position of the elevator in the frontal and horizontal planes

The position of the elevator in the frontal plane is determined by the angle β between the projection of the working part of the elevator onto the frontal plane and the transverse axis (Fig. 1). The most rational approach appears to be positioning the elevator as horizontally as possible, as this orientation corresponds to the maximum length of the lever's longer arm (Fig. 2).

In Fig. 2, the horizontal position of the working part of the elevator is depicted in red.

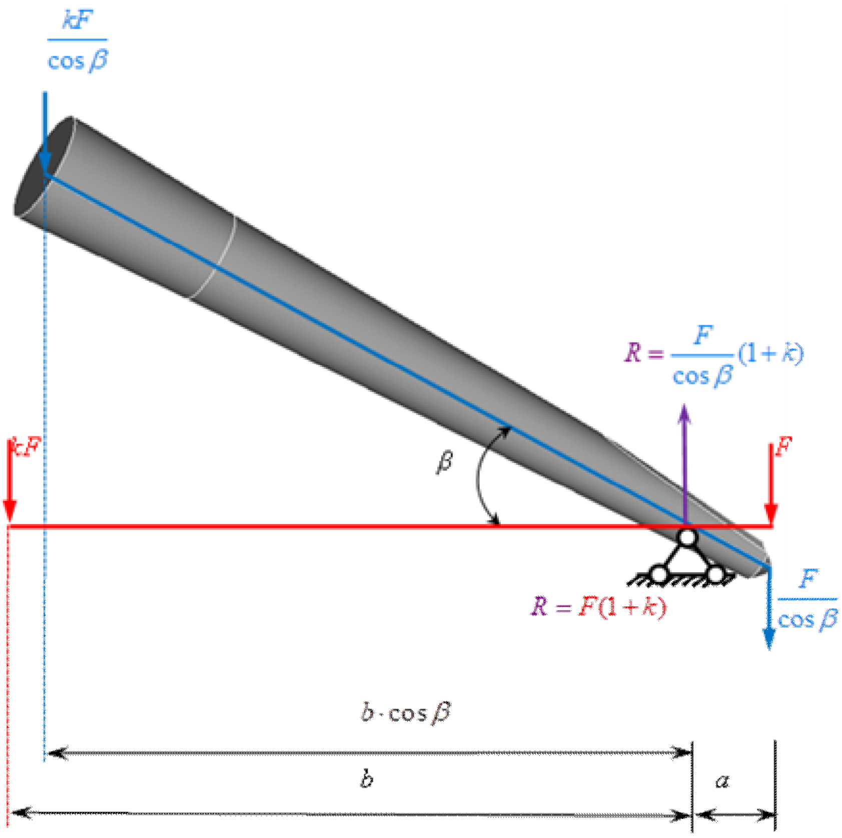

Figure 2. Schematic diagram of the working part of the elevator depending on its position in the frontal plane

On the shorter arm of the lever, the force *F* required for tooth extraction is transmitted through the cheek of the elevator. On the longer arm of the elevator's working part, the dentist must apply a force *kF*, where *k* is the ratio of the right and left arms *k=a/b*. The fulcrum for the working part of the elevator is the apex of the alveolar process, which bears both loads. Thus, the support reaction *R* at the point of contact between the working part of the elevator and the alveolar process will be equal to the sum of the two loads $R = kF + F = F(1+k)$. When the elevator is rotated from the horizontal position in the frontal plane by an angle *β*, the arm of the vertical force applied to the working part of the elevator decreases and can be calculated as $b \cdot \cos\beta$. To achieve a force on the elevator's cheek equivalent to the force in the horizontal position, the dentist must apply a greater force equal to $kF/\cos\beta$. Consequently, the value of the support reaction *R* at the point of contact between the working part of the elevator and the alveolar process will also increase, becoming $R = (kF + F)/\cos\beta = F(1+k)/\cos\beta$.

It is also important to note that as the angle *β* increases, the horizontal component transmitted by the elevator's cheek in the bucco-lingual direction to the tooth being extracted also increases and can be determined as $F \cdot tg\beta/\cos\beta$. To quantitatively assess the increase in load from the working part of the elevator on the apex of the alveolar process, the values of $1/\cos\beta$, were calculated based on the derived relationships. These values determine how many times (or by what percentage) the load from the elevator increases at different positions depending on the angle *β*. The angle *β* was varied from 0° to 45° in increments of 5°.

Statistical analysis

Variational series were processed using the licensed software package GraphPad 2024 (GraphPad Software, Inc., USA). The results of three or more groups of data were compared using one-way analysis of variance (ANOVA) with Bonferroni correction. Differences in results were considered statistically significant at p-values less than 0.05.

Results

As evident from Table 1, when the angle β of the elevator's inclination to the horizontal plane changes from 0° to 25°, the increase in load on the apex of the alveolar process is negligible (not exceeding 10%). However, at angles β greater than 30°, the load exerted by the elevator on the alveolar process significantly increases (ranging from 15% to 41%). Thus, it is advisable to apply the maximum load on the tooth being extracted when the angle β of the elevator's inclination to the horizontal plane does not exceed 25°.

The analytical dependencies derived using classical mechanics methods for the localization and positioning of the dental elevator indicate only trends in the changes of maximum loads on the bone tissue of the alveolar process. This is because they do not account for the diversity of geometric shapes and physico-mechanical characteristics of the hard tissues in the dental arch.

Table 1

Increase in the load on the apex of the alveolar ridge at different positions of the elevator depending on the angle β between the projection of the working part of the elevator on the frontal plane and the transverse axis

The angle of inclination of the elevator relative to the horizontal plane, β (degrees).	Quantitative indicator of load increase $1/\cos\beta$	Percentage increase in load
0	1	0
5	1,004	0,4
10	1,015	1,5
15	1,035	3,5
20	1,064	6,4
25	1,103	10,3
30	1,155	15,5
35	1,221	22,1
40	1,305	30,5
45	1,414	41,4

Further assessment of the stress-strain state of the bone tissue in the alveolar process is most appropriately conducted using finite element modeling. This method allows for the consideration of both the diversity of geometric forms and the specific physical-mechanical characteristics of the hard tissues of the dentoalveolar complex.

The physical-mechanical characteristics of the individual structural components of the finite element model of the mandibular fragment are presented in Table 3, based on the values provided in Tables 1 and 2.

Table 2

Dimensions of the third molar used in the profile modeling

Morphometric parameters of the tooth:	Dimensions of the third molar, mm
Tooth height	16,5
Root height	11
Crown height	5,5
Vestibulo-lingual crown dimension	7,5
Vestibulo-lingual cervical dimension	6,5
Mesio-distal crown dimension	8,5
Mesio-distal cervical dimension	7,5

Table 3

Physical-mechanical characteristics of the structural components of the finite element model of the mandibular fragment

Material	Elastic modulus E, MPa	Poisson's ratio
Enamel of the tooth crown	$8{,}41 \cdot 10^4$	0,3
Dentin	$1{,}47 \cdot 10^4$	0,3
Cortical bone layer	$1{,}81 \cdot 10^4$	0,3
Spongy bone substance (trabecular bone)	$4{,}9 \cdot 10^2$	0,3
Periodontium	10	0,45

Given that the absolute values of the load do not have a significant impact on solving the posed problem (since any reference load value can be used to compare the maximum values of equivalent stresses arising at the point of contact between the working part of the elevator and the hard tissues of the alveolar process in different positions of the dental elevator), the calculated value of the vertical load distributed over the end of the working part of the elevator is assumed to be 10 N.

The study was conducted for four cases of the working part of the elevator positioned at angles β to the horizontal plane of 0º, 10º, 20º, and 30º, respectively. Based on the fact that, at different angles of inclination of the dental elevator, varying magnitudes of vertical forces can be transmitted to the third molar through the cheek of the working part of the elevator, which play a decisive role in tooth extraction, in addition to the stress-strain state of the hard tissues of the alveolar process, the vertical components of the load transmitted to the tooth were also determined (see Table 3).

The vertical component of the load on the third molar in the case of the working part of the elevator positioned at an angle β = 0º to the horizontal plane was taken as the reference. For the other three cases of the working part of the elevator positioned at angles of 10º, 20º, and 30º, the values of the vertical load distributed over the end of the working part of the elevator were adjusted in accordance with the reference vertical component of the load on the third molar in the case of the working part of the elevator positioned at an angle β = 0º.

The results of the conducted studies on the stress-strain state of the hard tissues of the alveolar process for the four cases of the working part of the elevator positioned at angles β to the horizontal plane of 0º, 10º, 20º, and 30º, respectively, are presented in Table 4. Additionally, the percentages of increase in the maximum values of equivalent stresses in the tissues of the alveolar process with an increase in the angle β relative to the horizontal position of the working part of the elevator are calculated there.

The distribution fields of equivalent stresses in the tissues of the alveolar process for the considered cases of the working part of the elevator's positioning are shown in Fig. 3.

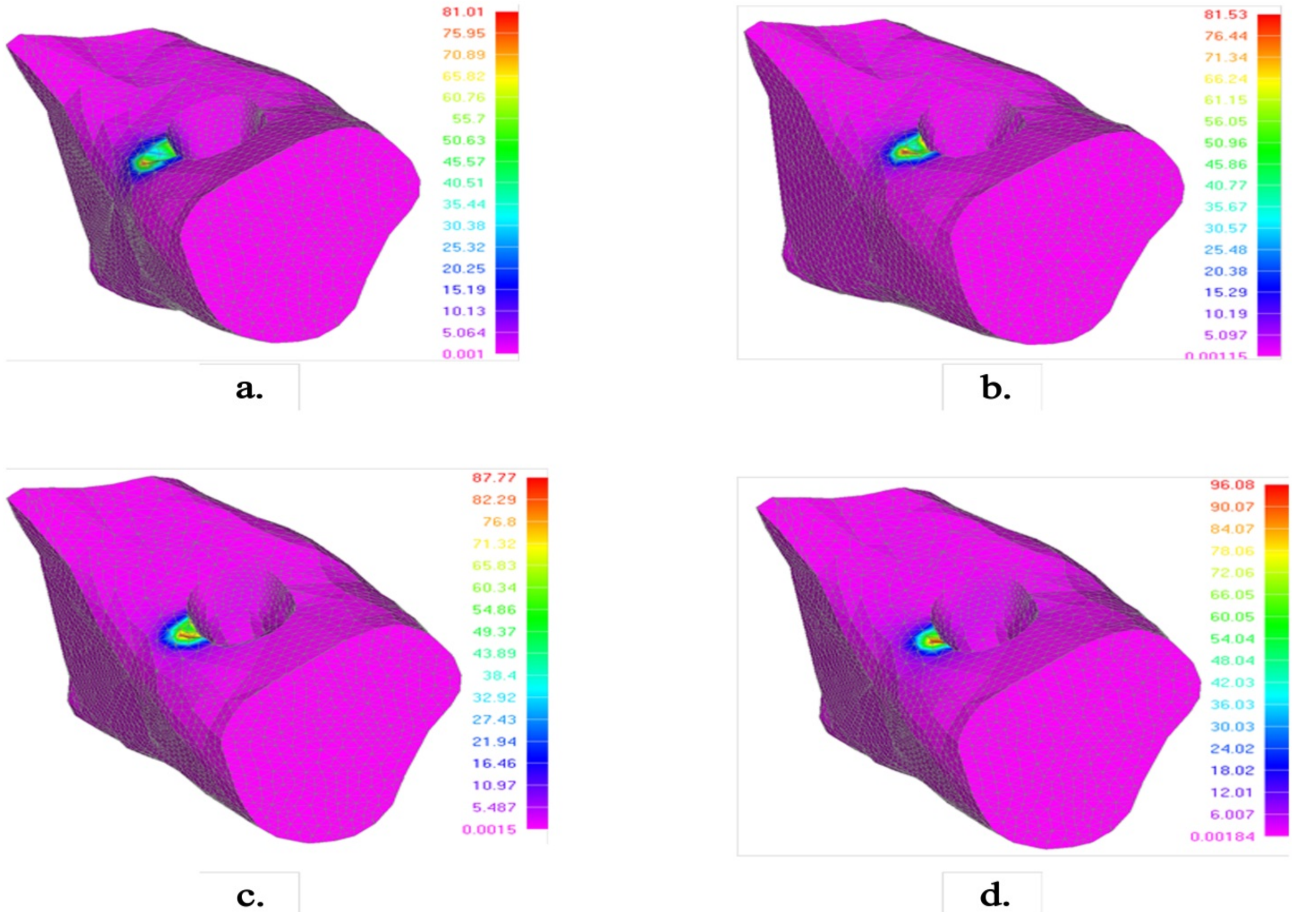

Figure 3. Distribution fields of equivalent stresses in the tissues of the alveolar process for the considered cases of the working part of the elevator positioned at angles: a) –0º; b) –10º; c) –20º; d) –30º relative to the horizontal plane.

As can be seen from Fig. 3 and Table 4, when the elevator is positioned at an angle of up to 20–25º relative to the horizontal plane, the maximum values of equivalent stresses in the tissues of the alveolar process differ insignificantly (differences do not exceed 10%). Considering that the maximum load on the tissues of the alveolar process does not occur at the beginning of its application but after a minimal vertical displacement of the third molar, likely due to the deformation of the periodontal ligaments, the initial insertion angle of the dental elevator should be increased by 10–15º.

Table 4
Maximum values of equivalent stresses in the tissues of the alveolar process for different cases of the working part of the elevator's positioning

Angle of inclination of the elevator relative to the horizontal plane, β (degrees)	Maximum values of equivalent stresses, MPa	Deviation of the maximum values of equivalent stresses from the corresponding values at the horizontal position of the elevator, %.
0	81,01	0,0
10	81,53	0,6
20	87,77	8,3
30	96,08	18,6

Thus, as the recommended angle for positioning the dental elevator at the beginning of the extraction of the third molar, an inclination angle of the working part of the dental elevator of 35–40º relative to the horizontal plane can be suggested.

Discussion

Tooth extraction surgery continues to dominate among all surgical interventions, including those in oral and maxillofacial surgery. The technique for performing this procedure is primarily based on the surgeon's experience and does not always take into account the mathematical rationale for the direction of force application with a luxator. This can lead to adverse outcomes, such as iatrogenic fractures of the mandible, traumatic injuries to the inferior alveolar nerve, inflammatory complications, mandibular contracture, and others, as well as an increase in the patient's recovery time. This, in turn, contributes to negative socio-economic dynamics [2; 9; 20]. Researchers and clinicians have paid some attention to techniques for bone tissue removal in cases of retention and dystopia of the lower third molar. For this purpose, the geometric shape of the removed fragment and the instrument used for the procedure are critically important. A significant difference in outcomes is observed when using a drill versus a piezotome [1; 8].

The technique of using autologous blood concentrates is also quite widespread and is applied not only to optimize the healing of the extraction socket but also in the treatment of jaw fractures, sinus lifting, and the removal of benign soft tissue lesions [21; 22].

The technique of coronectomy in cases of unfavorable positioning of the lower third molar is relatively common and is frequently mentioned in the analysis of literature. The use of coronectomy helps reduce the risk of injury to the mandibular canal, jaw fracture, and the formation of a large bone tissue defect. This results in lower trauma associated with this surgical intervention [1; 7].

Given that the percentage of impacted and malpositioned lower molars remains high within the population, the issue of minimizing trauma during both routine and complex tooth extractions continues to be highly relevant [9; 20; 23]. Determining the optimal angle of inclination for the luxator will enhance the surgeon's efficiency and provide not only an empirical but also a mathematical model for the surgical intervention involving the removal of a mesially inclined lower third molar.

Our study has several limitations. During the course of this research, we did not account for the influence of factors such as lifestyle, dietary habits, and, most importantly, the type of bone tissue, which could significantly impact the outcomes of subsequent studies. Additionally, the type of patients' occlusion and the degree of retention of the mesially inclined lower third molar were not considered.

Conclusion

The positioning of the fulcrum point for the working part of the elevator on the crest of the alveolar ridge should be as close as possible to the angle of the mandible. This is determined by the anatomical feasibility of positioning the elevator handle closer to the ramus of the mandible;

As the angle of inclination of the working part of the dental elevator relative to the horizontal plane increases, the maximum values of equivalent stresses in the tissues of the alveolar ridge beneath the fulcrum point of the elevator's working part also increase;

When the angle of inclination of the working part of the dental elevator relative to the horizontal plane does not exceed 20–25°, the increase in maximum values of equivalent stresses in the tissues of the alveolar ridge can be considered negligible. However, at greater angles of inclination, a sharp rise in the values of equivalent stresses is observed;

Considering the period during which maximum values of equivalent stresses occur in the tissues of the alveolar ridge (at the moment of periodontal ligament rupture) and the reduction of the dental elevator's angle of inclination relative to the horizontal plane by 10–15° at this moment, the recommended initial angle of inclination of the working part of the dental elevator relative to the horizontal plane during the extraction of the third molar is 35–40°.

Authors' contribution

The authors acknowledge their contribution to the work as follows: study concept and design: Avetikov D.S., Fenko O.; data collection: Avetikov H.D., Steblovskyi D.V., Skikevych M.G.; analysis and interpretation of results: Avetikov H.D., Fenko O.H.; preparation of the manuscript for publication: Lokes K.P., Toropov O.A. All authors reviewed the results and approved the final manuscript.

Conflict of interest

All authors declare that we do not have any conflict of interest (financial or other) other than those declared.

Use of Artificial Intelligence

The authors affirm that artificial intelligence was not utilized in the writing of this article.

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Стаття надійшла
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Abstract

Introduction. The removal of mesially inclined, impacted lower third molars continues to pose a complex challenge in dental surgery due to their frequent impaction, dystopia, and intricate topographic relationship with anatomical structures, particularly the inferior alveolar nerve.

Materials and methods. The biomechanical analysis and mathematical model were developed using the FEMAP 10.2.0 software. This method enables the optimization of dental luxators, reducing the load on the alveolar bone and periodontium.

Results. The angle β of the elevator's inclination to the horizontal plane changes from 0° to 25°, the increase in load on the apex of the alveolar process is negligible (not exceeding 10%). However, at angles β greater than 30°, the load exerted by the elevator on the alveolar process significantly increases (ranging from 15% to 41%). It is advisable to apply the maximum load on the tooth being extracted when the angle β of the elevator's inclination to the horizontal plane does not exceed 25°. Given that the absolute values of the load do not have a significant impact on solving the posed problem (since any reference load value can be used to compare the maximum values of equivalent stresses arising at the point of contact between the working part of the elevator and the hard tissues of the alveolar process in different positions of the dental elevator), the calculated value of the vertical load distributed over the end of the working part of the elevator is assumed to be 10 N.

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Conclusion. The positioning of the fulcrum point for the elevator working part on the crest of the alveolar ridge should be as close as possible to the angle of the mandible. This is determined by the anatomical feasibility of positioning the elevator handle closer to the mandibular ramus.

Key words: biomechanical model, lower third molar, tooth extraction, mandible, bone tissue.

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ОБГРУНТУВАННЯ БІОМЕХАНІЧНОЇ МОДЕЛІ ЕКВІВАЛЕНТНИХ НАВАНТАЖЕНЬ В АЛЬВЕОЛЬНОМУ ВІДРОСТКУ ТА КУТА НАХИЛУ ДЕНТАЛЬНИХ ЛЮКСАТОРІВ ПРИ ОПЕРАЦІЇ ВИДАЛЕННЯ ЗУБІВ

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Резюме

Вступ. Видалення мезіально нахилених, ретинованих нижніх третіх молярів продовжує становити складну проблему в стоматологічній хірургії через їх часту ретенцію, дистопію і складні топографічні взаємозв'язки з анатомічними структурами, зокрема з нижнім альвеолярним нервом.

Матеріали і методи. Біомеханічний аналіз і математичну модель було розроблено за допомогою програмного забезпечення FEMAP 10.2.0. Цей метод дозволяє оптимізувати зубні люксатори, зменшуючи навантаження на альвеолярну кістку і пародонт.

Результати. Кут β нахилу елеватора до горизонтальної площини змінюється від 0° до 25°, збільшення навантаження на верхівку альвеолярного відростка незначне (не перевищує 10%). Однак при кутах β більше 30° навантаження, що чиниться елеватором на альвеолярний відросток, значно зростає (від 15% до 41%). Доцільно застосовувати максимальне навантаження на зуб, що видаляється, коли кут β нахилу елеватора до горизонтальної площини не перевищує 25°. Враховуючи те, що абсолютні значення навантаження не мають суттєвого впливу на виконання поставленого завдання (оскільки будь-яке еталонне значення навантаження може бути використане для порівняння максимальних значень еквівалентних напружень, що виникають у точці контакту робочої частини елеватора і твердих тканин альвеолярного відростка в різних положеннях зубного елеватора), розрахункове значення вертикального навантаження, розподіленого по торцю робочої частини елеватора, приймається рівним 10 Н.

Подальшу оцінку напружено-деформованого стану кісткової тканини альвеолярного відростка найдоцільніше виконувати за допомогою моделювання методом скінченних елементів. Цей метод дозволяє враховувати і різноманітність геометричних форм, і специфічні фізико-механічні характеристики твердих тканин зубощелепного комплексу.

Висновок. Розташування точки опори робочої частини елеватора на гребені альвеолярного відростка має бути якомога ближчим до кута нижньої щелепи. Це визначається анатомічною доцільністю розташування ручки елеватора ближче до гілки нижньої щелепи.

Ключові слова: біомеханічна модель, нижній третій моляр, видалення зуба, нижня щелепа, кісткова тканина.