УДК 616.314-089.818.1-023.831: 616.314.17-002
DOI https://doi.org/10.35220/2078-8916-2022-45-3.12

O.O. Fastovets,
Doctor of Medical Sciences, Professor, Department of Prosthetic Dentistry, 9 Vernadsky, Dnipro, Ukraine, postal code 49044, fastovets.ol.ol@gmail.com

O.O. Hlazunov,
Post-Graduate Student, Department of Prosthetic Dentistry, 9 Vernadsky, Dnipro, Ukraine, postal code 49044, sasha-glazynov@bigmir.net

THE EFFECT OF CONVERGENCE ANGLE OF TOOTH PREPARATION IN PATIENTS WITH GENERAL PERIODONTITIS ACCORDING FINITE ELEMENT ANALYSIS

Purpose of the research. *To study the character of displacement and stress distribution after prosthetics of the lower central incisor with the metal-ceramic crown, depending on the convergence angle of preparation and the degree of resorption of alveolar septa using finite element analysis.* ***Research methods.*** *The computer models have been studied using the calculated software complex “Lira 9.6” to reproduce intact (before preparation) and treated teeth, taking into account subsequent imposition of a metal-ceramic crown. Calculations have been made for different convergence angles, from* 2^0 *to the maximum possible, for four types of loads (constant from own weight; vertical from food biting off; at an angle of* 30^0 *to vertical; at an angle of* 45^0 *to vertical) and for different degrees of preservation of alveolar septa: 100 %, 75 % and 50 %.* ***Scientific novelty.*** *It has been established that in the calculated model the increase of the convergence angle of tooth surfaces, as well as the decrease in alveolar septa height, cause the increase in displacements in the biomechanical system “crown – tooth – alveolar bone”, the maximum of which are localized in the neck area of the tooth on its lingual surface. The increase in the angle of preparation causes the increase in stresses in the same area, while the increase in the degree of resorption of alveolar septa results with the displacement of the maximum stress zone from the tooth neck to the apical part of the root.* ***Conclusions.*** *The obtained results indicate the need for tooth preparation with the minimum convergence angle of surfaces in patients with general periodontitis. It could prevent the risks of the progression of the pathological process in periodontal tissues due to the increase of stresses and displacements.*

Key words: *finite element method, displacement and stress distribution, tooth preparation, general periodontitis.*

О.О. Фастовець,
доктор медичних наук, професор, кафедра ортопедичної стоматології, Дніпровський державний медичний університет, вул. Вернадського, 9, м. Дніпро, Україна, індекс 49044, fastovets.ol.ol@gmail.com

О.О. Глазунов,
аспірант, кафедра ортопедичної стоматології, Дніпровський державний медичний університет, вул. Вернадського, 9, м. Дніпро, Україна, індекс 49044, sasha-glazynov@bigmir.net

ВПЛИВ КУТА КОНВЕРГЕНЦІЇ ПОВЕРХОНЬ ПРИ ПРЕПАРУВАННІ ЗУБІВ У ХВОРИХ НА ГЕНЕРАЛІЗОВАНИЙ ПАРОДОНТИТ ЗГІДНО АНАЛІЗУ КІНЦЕВИХ ЕЛЕМЕНТІВ

Мета дослідження. *Вивчити характер переміщень та розподіл напруг при протезуванні нижнього центрального різця металокерамічною коронкою в залежності від кута конусності препарування та ступеня резорбції альвеолярної перегородки із застосуванням методу кінцевих елементів.* ***Методи дослідження.*** *Створені комп’ютерні моделі вивчались із використанням розрахункового програмного комплексу «Ліра 9.6» для відтворення інтактного (до препарування) та препарованого зуба, з урахуванням подальшого накладання металокерамічної коронки. Розрахунки проводились для різних кутів конвергенції, починаючи з* 2^0 *до максимально можливого, для чотирьох видів навантажень (постійного від власної ваги; вертикального від відкушування їжі; під кутом* 30^0 *до вертикалі; під кутом* 45^0 *до вертикалі) та для різних ступенів збереження міжальвеолярних перегородок: 100 %, 75 % та 50 %.* ***Наукова новизна.*** *Встановлено, що збільшення в розрахунковій моделі кута конвергенції поверхонь зуба, також як і зменшення висоти альвеолярної перегородки, призводять до зростання переміщень в біомеханічній системі «коронка – зуб – кісткова альвеола», максимальні з яких локалізовані в пришийковій ділянці зуба з язикової поверхні. Збільшення кута при препаруванні викликає зростання напруг в тій же ділянці, тоді як зростання ступеня резорбції міжальвеолярних перегородок спричинює зміщення зони максимальної напруги від шийки зуба до апікальної частини кореня.* ***Висновки.*** *Отримані результати вказують на необхідність додержання при препаруванні мінімального кута конвергенції поверхонь зуба у хворих на генералізований пародонтит, що дозволить знизити ризики прогресування патологічного процесу в навколозубних тканинах внаслідок зростання напружено-деформованих станів.*

Ключові слова: *метод кінцевих елементів, напружено-деформовані стани, препарування зубів, генералізований пародонтит.*

Posing a problem. The use of the finite element (FE) method for study of the stress and deformation distribution in the biomechanical system "denture – prosthetic bed" in their interaction during chewing load allows to determine the areas of stress concentration and ways to avoid them. It makes possible to substantiate the tactics of prosthetic treatment of defects of teeth and dentitions, in particular, the peculiarities of the prosthetic bed preparation, choose the most effective dentures designs and materials for their manufacture [1, p. 242-250; 2, p. 96-108; 3, p. 3-13]. It should be noted that the study of the stress and deformation distribution in fixed dentures is mainly aimed at the prevention of fractures of supporting teeth [4, p. 505-509], occlusion overload [5, p. 395-400] and damage of the marginal periodontal tissues [6, p. 6113], which are the consequences of inadequate stress increases in irrational dental prosthetics. It is known that in fixed prosthetics, the chamfer design, not its size, determines the stress distribution in the tooth neck area [7, p. 1168-1175]. In the research [8, p. 30], they show the importance of observing the angle of 20° when creating the chamfer. In turn, minimally invasive endodontics and biologically oriented preparation technique could significantly reduce stresses on the restorations [9, p.642-647; 10, p. 480-484; 4, p. 505-509; 6, p. 6113], but at the same time it worsens the dentures retention.

However, information about the effect of preparation on the stress distribution in crowns and supporting teeth is limited and contradictory [11, p. 871-877]. Thus, it is proved that when prosthetics with all-ceramic designs, the height of the preparated teeth plays a greater role in the stress distribution than the convergence angle [12, p. 436-442]. Oppositely, in the research [11, p. 871-877] it has been indicated that differences in the preparation design do not cause the difference in the stress distribution in pulp, dentin or bone.

In addition, it should also be took into account that the individual nature of the stress and deformation distribution is determined by a number of factors that describe the clinical situation, among which the state of periodontal tissues is leading (in the simulation model it describes with the height of the preserved alveolar septa) [13, p. 295-302; 14, p. 265-269; 15, p. 214-221], as well as secondary traumatic occlusion [5, p. 395-400].

In connection with these data, we have recognized as expedient to investigate the influence of the design of tooth preparation, in particular the convergence angle of the surfaces of the supporting tooth, on the character of the stress and displacement distribution depending on the condition of the periodontal tissues, namely the volume of preservation of the alveolar septa at different degrees of severity of general periodontitis.

In our opinion, established peculiarities allow to justify teeth preparation technique, which gives the decrease of the stress and deformation distribution in the biomechanical system "crown – tooth – bone". It decreases risks of progress of pathological process in periodontal tissues due to increased occlusion load, thus prevention of possible complications.

So, **the purpose of this research** is to study the character of displacement and stress distribution after prosthetics of the lower central incisor with the metal-ceramic crown, depending on the convergence angle of preparation and the degree of resorption of alveolar septa using finite element analysis.

Research methods. The study of the stress and displacement distribution has been done for a right central incisor of a mandible, taking into account its covering with a metal-ceramic crown. The created computer models have been studied using the calculated software complex "Lira 9.6" using the finite element (FE) method to reproduce intact tooth (before preparation) and prepared one (after preparation at different angles) with fixed metal-ceramic crown and simulating possible functional loads.

The algorithm of the study was as follows. First of all, we have developed a basic computer model of a conventional right central incisor of a mandible, which has been later used to simulate various clinical situations (**Fig**. 1). To create the basic computer model, in the initial FE system it has been taken the medial sizes of the tooth crossing, the contours of the preparation, the cement layer, the contours of the metal cap and the contours of the crown. Depending on the angles of preparation, the contours of the above surfaces of the base model have been changed. With the increase in the angle of preparation, the outer contours of the crown on the tooth have not change, but at the same time the thickness of the ceramic layer of the crown has increased. In addition, at the level of the crown edge, by busting possible options, the symbol of the chamfer has been simulated, the shape of which at the cross-section was trapezoidal.

To create the models, we have used the physical and mechanical characteristics of the tissues and materials, which have been given in **Table**.

Calculations have been made for different convergence angles, starting from 2^0 to the maximum possible. Movement and deformation as well as the stress distribution in the FE system have been carried out for four types of loads: constant load from the own

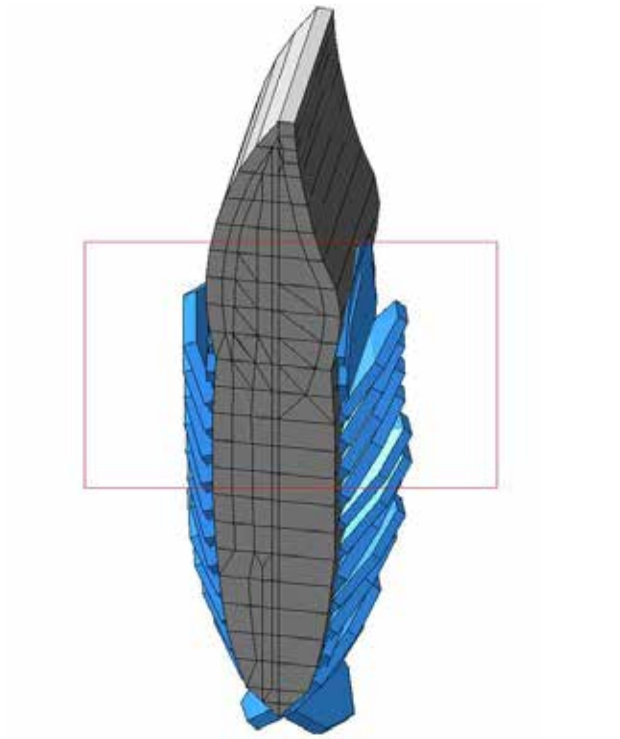

Fig. 1. General view of the three-dimensional base model (side view).

weight of the FE, which was calculated by the program automatically, depending on the hardness of the FE; under the influence of a force of 100 N – vertical load from food biting off; load at an angle of 30^0 to the vertical; load at an angle of 45^0 to the vertical. It has been received the data for each load separately, and then for their combination in different variants of calculated situations.

In addition, the stress and displacement distribution has been studied on computer models, which took into account three degrees of preservation of interalveolar septa: 100 %, 75 % and 50 %, which corresponded to the state of bone tissue of healthy periodontal tissues, periodontitis of the I and II degrees of severity respectively.

As the result of the calculation of developed computer models, it has been detected the movement of nodes, the stress distribution in intact and crown-covered teeth. In the process of computer analysis using the FE method, the main movements and deformations in the nodes of the design models have been found, the stress distribution in the FE have been determined, which have been demonstrated in the form of visual mosaics of the calculated parameters from each created combination of loads of studied models. Further, the analysis of the results of calculations and clarification of equivalent stresses according to Mises and maximum displacement values has been carried out. For the possibility of further analysis of the influence of the preparation angles on the stress and deformations distribution of the calculated models, all the values in the FE have been calculated for the cutting edge, the equator, the neck, the middle area of the root and the tooth apex.

The obtained data has been processed statistically with a licensed software product MS Excel 2003 [16, 558 p.].

Results and discussion. During the study, we have obtained 36 calculated models that differed from each other in the presence of the artificial crown, the peculiarities of tooth preparation (different convergence angle), the degree of preservation of interalveolar septa, and the type of load.

We have to note immediately that the stress and displacement distribution has been determined by the type of loads, but it has been characterized by the similarity of the stress and displacement redistribution in various simulation models, the difference has been in their intensity. The most indicative of the current study have been the results obtained for loading at an angle of 45^0 to the vertical (**fig**. 2-7).

After the calculations, due to the imitation of tooth prosthetics with a metal-ceramic crown, the increase in the stress and deformation distribution has been detected. Thus, the increase of the con-

Table 1

Physical and mechanical characteristics of tissues and materials used in calculated computer models

Tissue/material	Elasticity module, MPa	Poisson coefficient	Density, mN/m³
Enamel	76 000	0.31	0.03706
Dentin of crown	15 000	0.31	0.018
Dentin of root	15600	0.31	0.01962
Cement of tooth	10000	0.3	0.018
Periodontal ligament	20 000	0.3	0.02
Bone tissue of alveolar septa	13 700	0.3	0.01962
Nickel-chrome alloy	210 000	0.3	0.07701
Ceramic mass	68 800	0.22	0.01962
Glass-ionomer cement	12 000	0.25	0.01966

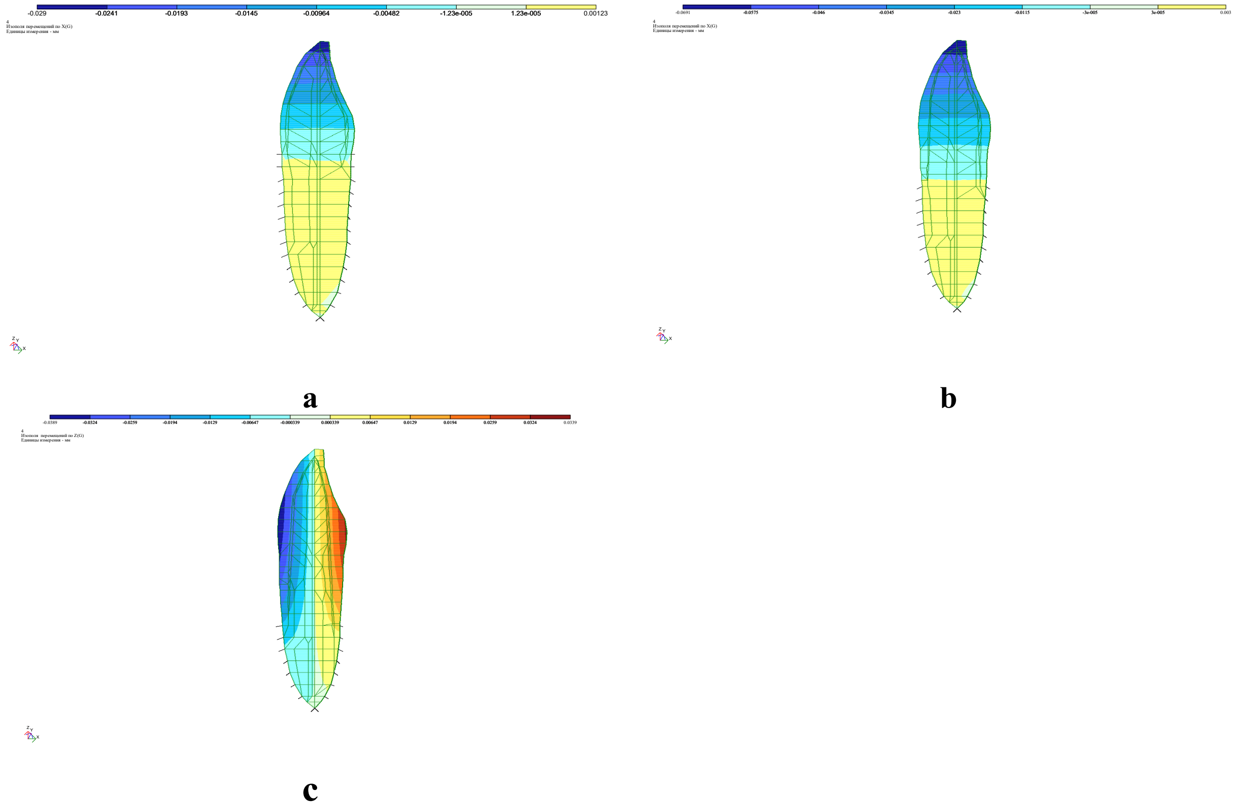

Fig. 2. The fields of displacements of the intact tooth under the influence of load at an angle of 450 to the vertical in simulation models with varying degrees of preservation of the alveolar septa: a – 100 %; b – 75 %; c – 50 %

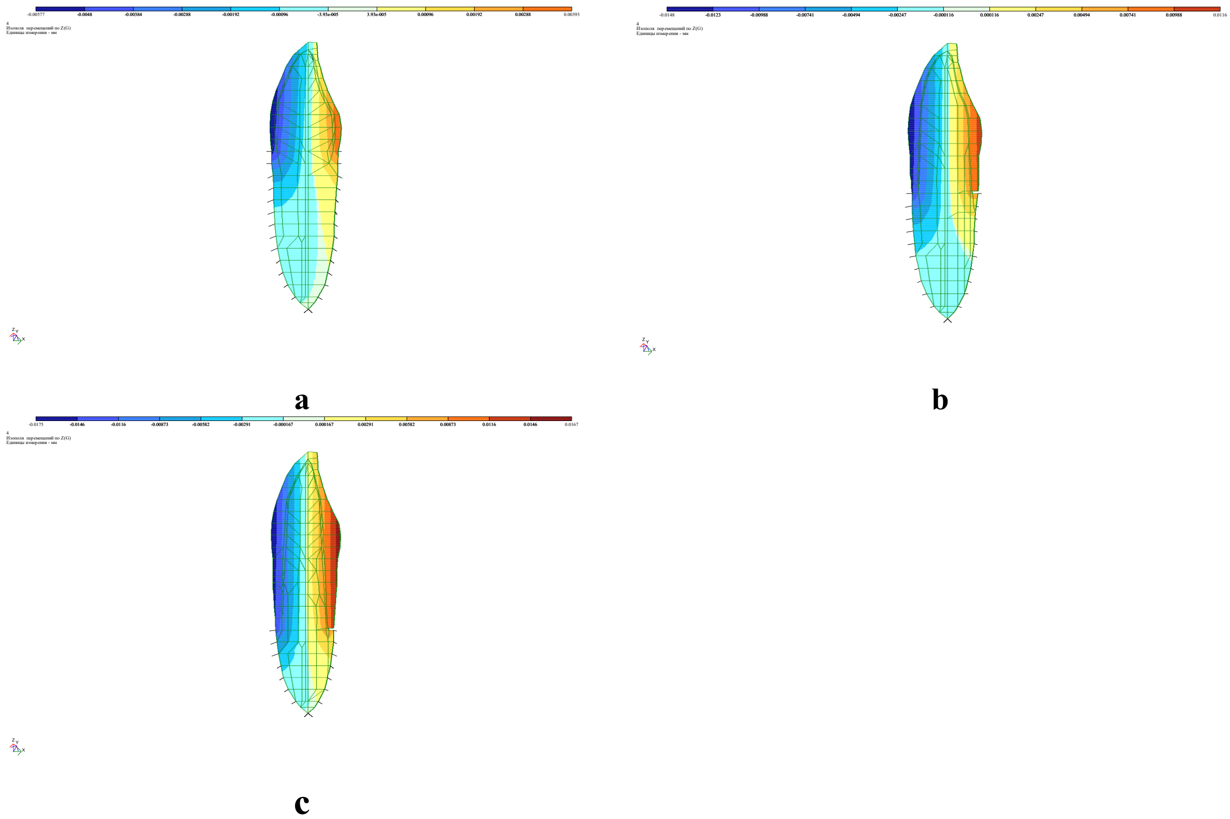

Fig. 3. The fields of displacements of the tooth, which is preparated with the minimum convergence angle and covered with the combined crown, under the influence of load at an angle of 450 to the vertical in simulation models with varying degrees of preservation of the alveolar septa: a – 100 %; b – 75 %; c – 50 %

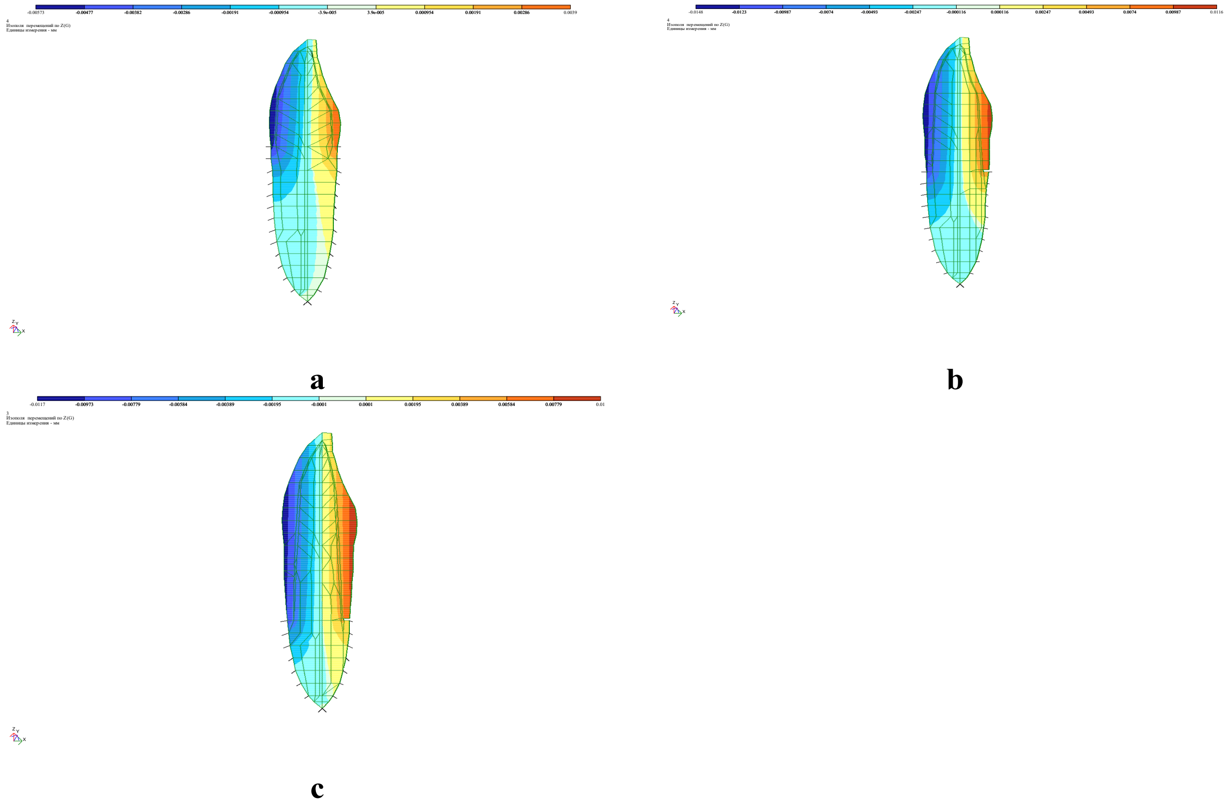

Fig. 4. The fields of displacements of the tooth, which is preparated with the maximal convergence angle covered with the combined crown, under the influence of load at an angle of 450 to the vertical in simulation models with varying degrees of preservation of the alveolar septa: a – 100 %; b – 75 %; c – 50 %

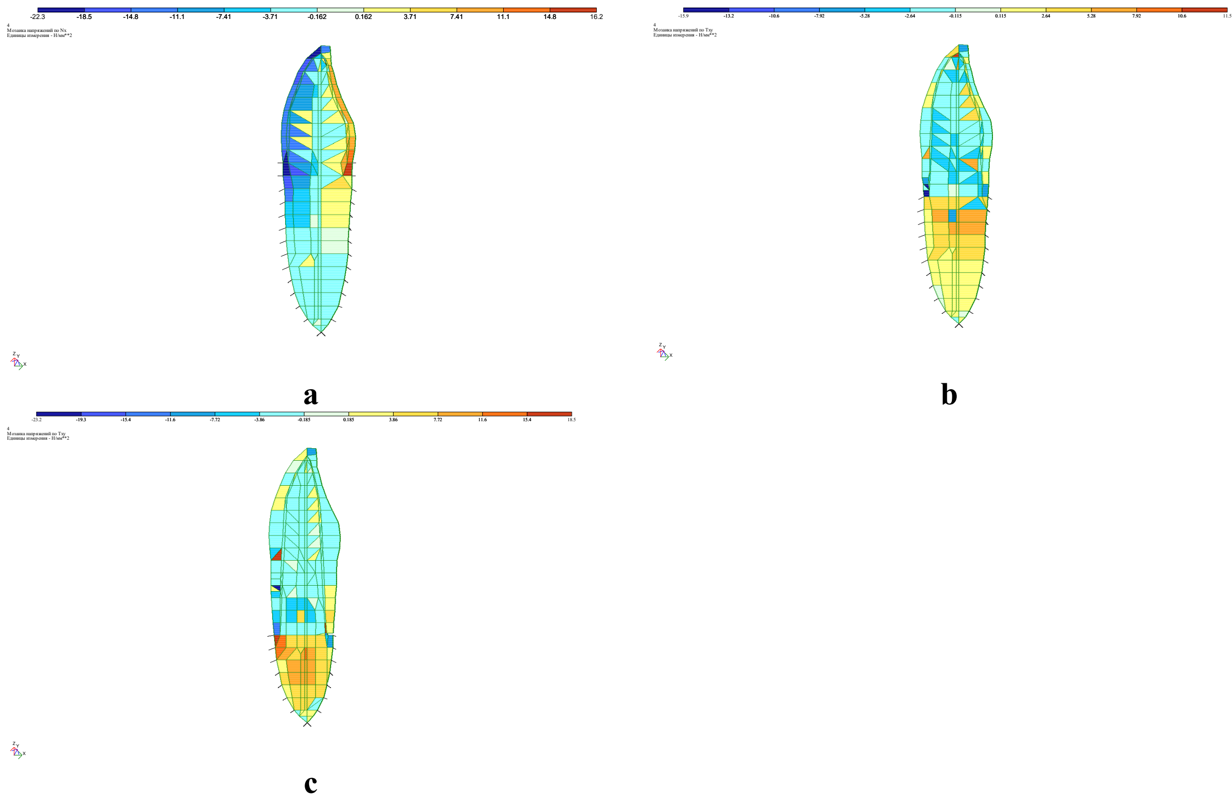

Fig. 5. The stress distribution in the intact tooth under the influence of load at an angle of 450 to the vertical in simulation models with varying degrees of preservation of the alveolar septa: a – 100 %; b – 75 %; c – 50 %

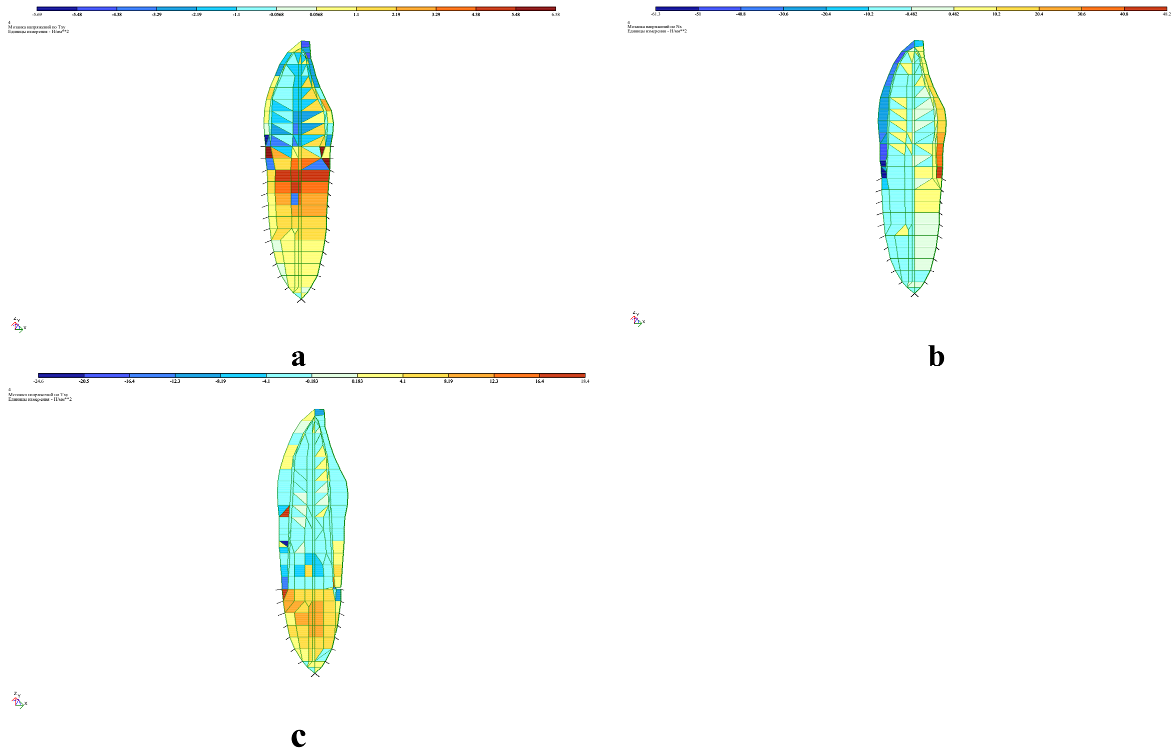

Fig. 6. The stress distribution in the tooth, which is preparated with the minimum convergence angle covered with the combined crown, under the influence of load at an angle of 450 to the vertical in simulation models with varying degrees of preservation of the alveolar septa: a – 100 %; b – 75 %; c – 50 %

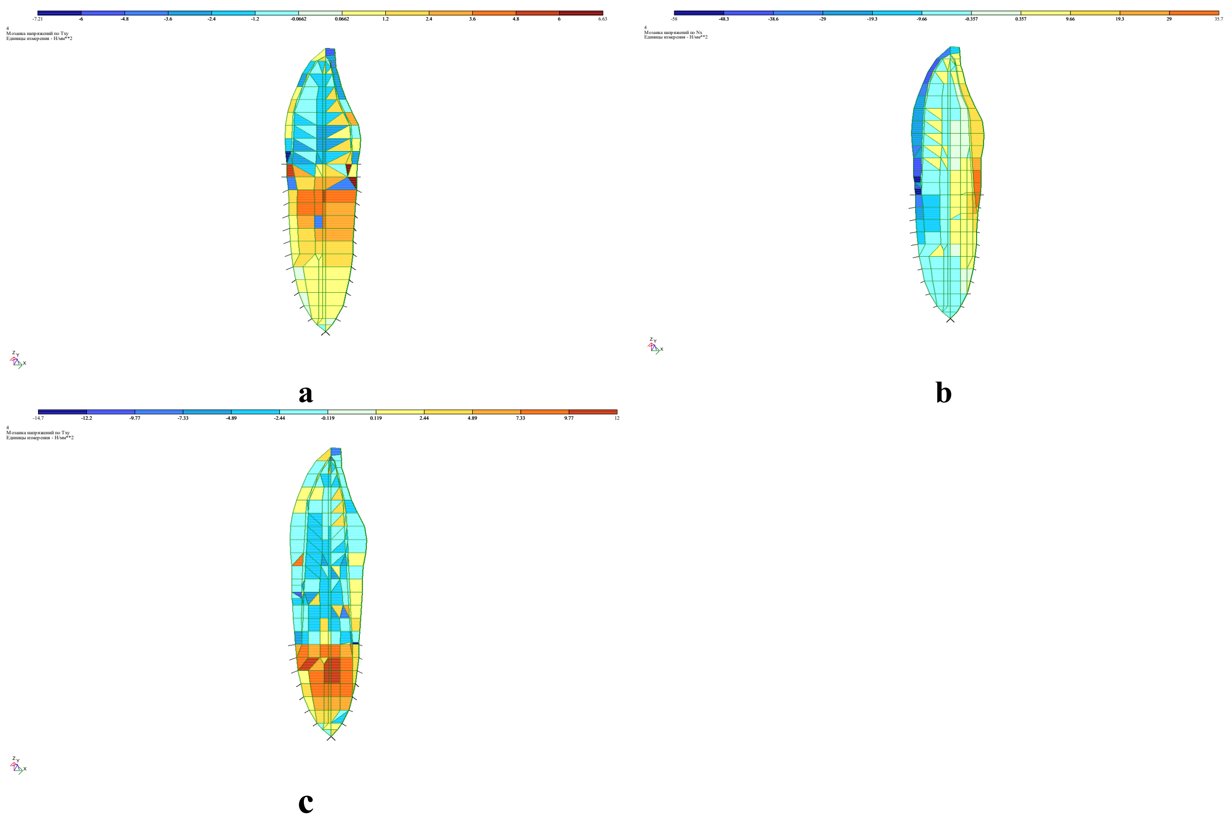

Fig. 7. The stress distribution in the tooth, which is preparated with the maximal convergence angle covered with the combined crown, under the influence of load at an angle of 450 to the vertical in simulation models with varying degrees of preservation of the alveolar septa: a – 100 %; b – 75 %; c – 50 %

vergence angle has led to the increase in the crown thickness. At the same time, the crown has taken on most of the stresses and unloaded the periodontal tissues. In **fig. 6a and 7a** one can see that in the area of contact of the crown edge with the chamfer and in the bone tissue of the alveolar septa, from the lingual surface, there are significant stresses that have located character and give the overload of the biomechanical system "crown – tooth – alveolar bone". In turn, the increase in the convergence angle of the preparated tooth surfaces has also led to the increase in displacements in studied biomechanical system. As you can see from fig. 3a and 4a, the maximum displacements have been mainly localized in the neck area of the tooth.

Accordingly, the degree of simulated resorption of the alveolar septa has also led to the redistribution of the stresses and displacements.

In the intact tooth, the growth of the degree of resorption of the interalveolar septa has caused the displacement of the maximum stress zone from the tooth neck (fig. 5a) to the apical part of the root (fig. 6a and 7a). This trend is more noticeable when covering the tooth with a combined crown with a preliminary preparation with a minimum convergence angle (fig. 5b, 6b, 7b) and it is most pronounced when creating a maximum cone of preparated tooth (fig. 5c, 6c, 7c).

As for the displacement fields, with the decrease in the height of the alveolar septa, the increase in areas of maximum displacement has been observed, localized mainly in the area of the tooth neck, when simulating an intact periodontal (fig. 2a, 3a, 4a) to spread on the lingual surfaces of the tooth crown and root while decreasing the height of the alveolar septa to 75% (fig. 2b, 3b, 4b) and to 50% (fig. 2c, 3c, 4c). At the same time, the largest displacements have been registered for resorbed interalveolar septa, which correspond to the periodontitis of the II degree of severity, when preparing a tooth at the maximum convergence angle (fig. 4c).

Conclusions. When prosthetics of teeth with combined crowns in patients with generalized periodontitis, the character of the displacements and maximum stress distribution according to Mises depends on the angle of cone of tooth preparation and the degree of resorption of bone tissue. The large convergence angle of the tooth which is prepared under the metal-ceramic crown and the significant degree of resorption of the interalveolar septa give a critical redistribution of stresses and displacements.

In clinical conditions, with a high degree of probability, this situation contributes to the development of traumatic marginal periodontitis, which is manifested by the primary destruction of the periodontal ligament and alveolar bone and causes deterioration in the course of the pathological process in periodontal tissues.

Registered changes of the stress and deformation distribution in the above-described simulation models prove the need to observe the minimum convergence angle in tooth preparation in patients with general periodontitis, in particular for splint designs, which allow increasing the functional efficiency and sufficient stability to the occlusion load of biomechanical system "crown – tooth – bone".

Література:

1. Tang Z.W., Shi W.H., Xia B., Yang J.Y., Zhao Y.J. & Wang Y. (2022). Design of non-metallic crown for primary molars and analyze of stress distribution: a finite element study. *Zhonghua Kou Qiang Yi Xue Za Zhi,* 57 (3), 242-250. https://doi:10.3760/cma.j.cn112144-20210513-00227 [in Chinese].

2. Gaziano P., Lorenzi C., Bianchi D., Monaldo E., Dolci A. & Vairo G. (2020). Mechanical performance of Anatomic-Functional-Geometry dental treatments: A computational study. *Medical Engineering& Physics,* 86, 96-108. https://doi: 10.1016/j.medengphy.2020.10.016.

3. Corrêa G., Brondani L. P., Wandscher V. F., Pereira G. K. R., Valandro L. F. & Bergoli C. D. (2018). Influence of remaining coronal thickness and height on biomechanical behaviour of endodontically treated teeth: survival rates, load to fracture and finite element analysis. *Journal of Applied Oral Sciences*, 26, e20170313. https://doi:10.1590/1678-7757-2017-0313.

4. Allen C., Meyer C. A., Yoo E., Vargas J. A., Liu Y. & Jalali P. (2018). Stress distribution in a tooth treated through minimally invasive access compared to one treated through traditional access: A finite element analysis study. *Journal of Conservative Dentistry*, 21 (5), 505-509. https://doi:10.4103/JCD.JCD_260_18.

5. Reddy R. T. & Vandana K. L. (2018). Effect of hyperfunctional occlusal loads on periodontium: A three-dimensional finite element analysis. *Journal of Indian Society of Periodontology*, 22 (5), 395-400. https://doi:10.4103/jisp.jisp_29_18.

6. Sichi L.G. B., Pierre F.Z., Arcila L.V. C, de Andrade G.S., Tribst J.P.M., Ausiello P., di Lauro A.E. & Borges A.L.S. (2021). Effect of biologically oriented preparation technique on the stress concentration of endodontically treated upper central incisor restored with zirconia crown: 3D-FEA. *Molecules,* 26 (20), 6113. https://doi:10.3390/molecules26206113.

7. Zhang L., Ye N., Aregawi W.A. & Fok A. (2021). Effect of chamfer design on load capacity of reattached incisors. *Dental Materials*, 37 (7), 1168-1175. https://doi:10.1016/j.dental.2021.04.003.

8. Zheng Z., Sun J., Jiang L., Wu Y., He J., Ruan W. & Yan W. (2022). Influence of margin design and restorative material on the stress distribution of endocrowns: a 3D finite element analysis. *BMC Oral Health*, 22 (1), 30. https://doi:10.1186/s12903-022-02063-y.

9. Liu Z.Y., Zhao L., Yang L.Y. & Gao X. (2019). Three-dimensional finite element analysis of different endodontic access methods and full crown restoration in the maxillary central incisor. *Hua Xi Kou Qiang Yi Xue Za Zhi,* 37 (6), 642-647. https://doi:10.7518/hxkq.2019.06.013 [in Chinese].

10. Zhai X.Y., Zhang J.Y., Zhang S.K., Jiang C.J. & Qiu X.X. (2019). Finite-element analysis of mandibular first molar with two marginal designs of endocrown for the repair of different defects. *Hua Xi Kou Qiang Yi Xue Za Zhi.* 37 (5), 480-484. https://doi:10.7518/hxkq.2019.05.005 [in Chinese].

11. Oyar P., Ulusoy M. & Eskitaşçıoğlu G. (2014). Finite element analysis of stress distribution in ceramic crowns fabricated with different tooth preparation designs. *Journal of Prosthetic Dentistry*, 112 (4), 871-877. https://doi:10.1016/j.prosdent.2013.12.019.

12. Maghami E., Homaei E., Farhangdoost K., Pow E. H. N., Matinlinna J. P. & Tsoi J. K. (2018). Effect of preparation design for all-ceramic restoration on maxillary premolar: a 3D finite element study. *Journal of Prosthodontic Research*, 62 (4), 436-442. https://doi:10.1016/j.jpor.2018.04.002.

13. Wu J., Liu Y., Li B., Wang D., Dong X. & Zhou J. (2021). Effects of different alveolar bone finite element models on the biomechanical responses of periodontal ligament. *Sheng Wu Yi Xue Gong Cheng Xue Za Zhi*, 38 (2), 295-302. https://doi:10.7507/1001-5515.202007048 [in Chinese].

14. Sun Z. T., Wang Y. C., Cui Y. M. & Sun Y. (2019). Finite element analysis of maxillary anterior teeth retraction of posterior teeth with different alveolar bone absorption heights under orthodontic force. *Hua Xi Kou Qiang Yi Xue Za Zhi*, 37 (3), 265-269. https://doi:10.7518/hxkq.2019.03.007 [in Chinese].

15. Gameiro G.H., Bocchiardo J.E., Dalstra M. & Cattaneo P.M. (2021). Individualization of the three-piece base arch mechanics according to various periodontal support levels: A finite element analysis. *Orthodontics and Craniofacial Research,* 24 (2), 214-221. https://doi:10.1111/ocr.12420.

16. Антомонов М.Ю. Математическая обработка и анализ медико-биологических данных. Киев: [б.и.], 2017. 558 с.

References:

1. Tang, Z.W., Shi, W.H., Xia, B., Yang, J.Y., Zhao, Y.J. & Wang, Y. (2022). Design of non-metallic crown for primary molars and analyze of stress distribution: a finite element study. *Zhonghua Kou Qiang Yi Xue Za Zhi,* 57 (3), 242-250. https://doi:10.3760/cma.j.cn112144-20210513-00227 [in Chinese].

2. Gaziano, P., Lorenzi, C., Bianchi, D., Monaldo, E., Dolci, A. & Vairo, G. (2020). Mechanical performance of Anatomic-Functional-Geometry dental treatments: A computational study. *Medical Engineering& Physics,* 86, 96-108. https://doi: 10.1016/j.medengphy.2020.10.016.

3. Corrêa, G., Brondani, L.P., Wandscher, V.F., Pereira, G.K.R., Valandro, L.F. & Bergoli, C.D. (2018). Influence of remaining coronal thickness and height on biomechanical behaviour of endodontically treated teeth: survival rates, load to fracture and finite element analysis. *Journal of Applied Oral Sciences*, 26, e20170313. https://doi:10.1590/1678-7757-2017-0313.

4. Allen, C., Meyer, C.A., Yoo, E., Vargas, J.A., Liu, Y. & Jalali, P. (2018). Stress distribution in a tooth treated through minimally invasive access compared to one treated through traditional access: A finite element analysis study. *Journal of Conservative Dentistry*, 21 (5), 505-509. https://doi:10.4103/JCD.JCD_260_18.

5. Reddy, R.T. & Vandana, K.L. (2018). Effect of hyperfunctional occlusal loads on periodontium: A three-dimensional finite element analysis. *Journal of Indian Society of Periodontology*, 22 (5), 395-400. https://doi:10.4103/jisp.jisp_29_18.

6. Sichi, L.G.B., Pierre, F.Z., Arcila, L.V. C, de Andrade, G.S., Tribst, J.P. M., Ausiello, P., di Lauro, A.E. & Borges, A.L. S. (2021). Effect of biologically oriented preparation technique on the stress concentration of endodontically treated upper central incisor restored with zirconia crown: 3D-FEA. *Molecules,* 26 (20), 6113. https://doi:10.3390/molecules26206113.

7. Zhang L., Ye N., Aregawi W.A. & Fok A. (2021). Effect of chamfer design on load capacity of reattached incisors. *Dental Materials*, 37 (7), 1168-1175. https://doi:10.1016/j.dental.2021.04.003.

8. Zheng, Z., Sun, J., Jiang, L., Wu, Y., He, J., Ruan, W. & Yan, W. (2022). Influence of margin design and restorative material on the stress distribution of endocrowns: a 3D finite element analysis. *BMC Oral Health*, 22 (1), 30. https://doi:10.1186/s12903-022-02063-y.

9. Liu, Z.Y., Zhao,L., Yang, L.Y. & Gao, X. (2019). Three-dimensional finite element analysis of different endodontic access methods and full crown restoration in the maxillary central incisor. *Hua Xi Kou Qiang Yi Xue Za Zhi,* 37 (6), 642-647. https://doi:10.7518/hxkq.2019.06.013 [in Chinese].

10. Zhai, X.Y., Zhang, J.Y., Zhang, S.K., Jiang, C.J. & Qiu, X.X. (2019). Finite-element analysis of mandibular first molar with two marginal designs of endocrown for the repair of different defects. *Hua Xi Kou Qiang Yi Xue Za Zhi.* 37 (5), 480-484. https://doi:10.7518/hxkq.2019.05.005 [in Chinese].

11. Oyar, P., Ulusoy, M. & Eskitaşçıoğlu, G. (2014). Finite element analysis of stress distribution in ceramic crowns fabricated with different tooth preparation designs. *Journal of Prosthetic Dentistry*, 112 (4), 871-877. https://doi:10.1016/j.prosdent.2013.12.019.

12. Maghami, E., Homaei, E., Farhangdoost, K., Pow, E.H.N., Matinlinna, J.P. & Tsoi, J.K. (2018). Effect of preparation design for all-ceramic restoration on maxillary premolar: a 3D finite element study. *Journal of Prosthodontic Research*, 62 (4), 436-442. https://doi:10.1016/j.jpor.2018.04.002.

13. Wu, J., Liu, Y., Li, B., Wang, D., Dong, X. & Zhou, J. (2021). Effects of different alveolar bone finite element models on the biomechanical responses of periodontal ligament. *Sheng Wu Yi Xue Gong Cheng Xue Za Zhi*, 38 (2), 295-302. https://doi:10.7507/1001-5515.202007048. [in Chinese].

14. Sun, Z.T., Wang, Y.C., Cui, Y.M. & Sun, Y. (2019). Finite element analysis of maxillary anterior teeth retraction of posterior teeth with different alveolar bone absorption heights under orthodontic force. *Hua Xi Kou Qiang Yi Xue Za Zhi*, 37 (3), 265-269. https://doi:10.7518/hxkq.2019.03.007 [in Chinese].

15. Gameiro, G.H., Bocchiardo, J.E., Dalstra, M. & Cattaneo, P.M. (2021). Individualization of the three-piece base arch mechanics according to various periodontal support levels: A finite element analysis. *Orthodontics and Craniofacial Research,* 24 (2), 214-221. https://doi:10.1111/ocr.12420.

16. Antomonov, M.Y. (2017). *Matematicheskaya obrabotka i analiz mediko-biologicheskikh dannykh [Mathematical processing and analysis of biomedical data]*. Kyiv [in Russian].