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# Influence of the angle of dental implant placement on the stress-strain state of the jaw

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***Abstract:*** *prosthetics on dental implants is a complex and responsible stage of treatment of patients with dental defects. The success of dental implantation depends not only on careful planning and performed surgical intervention in compliance with the requirements of the protocol, but also on the type of load on the dental implant, the choice of orthopedic design and material. Thorough preparation for prosthetics, taking into account the initial clinical situation and individual characteristics of the patient, ensures a full restoration of the dentition defect with reproduction of the chewing function. The parameters of the stress-strain state in the bone tissue around dental implants are of the greatest importance for the effectiveness of prosthetics on implants, especially in the long term of their functioning. Significant power loads of variable amplitude in the jaw lead to resorption of bone tissue and failure of implants as artificial dental prostheses. In this regard, research on modeling the stress-strain state in bone tissue under different loading conditions of implants is relevant. This research presents the results of studying the stress-strain state of the bone-implant system under static loading. Numerical calculations were performed for four installation angles of the implant: 0°, 7°, 15°, and 22°. The solid model of the mandible and the implant model were made in Spaceclaim software, and the stresses were determined using ANSYS Workbench. The results obtained show the effect of the implant placement angle on the distribution of stress fields in the bone tissue and implant. The analysis of the calculation results will help to ensure optimal functioning and durability of dental implants.*

**Keywords:** Computer Simulation, Dental Implants, Dental Stress Analysis, Finite Element Analysis, Mandible, stress.

## Introduction

The modern development of dentistry allows dental specialists to prevent the onset and progression of dental deformities by using dental implants. The last ones are increasingly used in everyday practice in comparison with bridges because they have a number of advantages (Dmytrenko I. A. & Ozhohan Z. R., 2014). However, along with the more frequent use of dental implants, there is a high level of secondary complications associated with their functioning in the crown-implant system. Today, special attention is paid to the biomechanical aspects of treatment in order to ensure acceptable levels of load on dental implants (Sahin S & Çehreli MC, 2001).

The rapid development of digital navigation technologies makes it possible to plan the crown before placing a dental implant, which is an urgent

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task. The study of the load distribution on the crown-implant-bone system is intended to use this knowledge to increase the duration of implant functioning in the patient's oral cavity.

**Aim**

The purpose of this study is to investigate the stress-strain states in the implant-bone area under static load at different implant angles.

**The object of research**

The research was conducted on a segment of the lower jaw with an implant installed in it (Fig. 1) (Baggi L. et al, 2008; Demenko et al, 2014). Using CT scanning, a cloud of points was obtained, which was used to build a surface body, and a solid body was obtained from it. The model was created in the Spaceclaim software package. For ease of fixation, the jaw section was mounted on a platform that required high stiffness compared to other components of the system, so structural steel was chosen as the platform material for calculations. The jaw was considered as a two-layer body: the outer layer is cortical bone tissue with a thickness of 2 mm, and the inner layer is trabecular. To simplify the calculations, we assumed linear elastic isotropic behavior of bone materials (Baggi L. et al, 2008). A simplified geometric model of the implant was used in the calculations. The mechanical properties of the materials are given in Table 1 (Baggi L. et al, 2008; Mohammed Ibrahim et al, 2011), where E – is the elastic modulus, μ – is the Poisson's ratio, and $\sigma_{crit}$ – is the critical stress.

According to the purpose of the research, 4 variants of implant placement in the jaw were considered: axially, at an angle of $7^{o}$, at an angle of $15^{o}$ and at an angle of $22^{o}$ (Fig. 2).

In this case, experimental studies to determine the stress-strain state of the system are a difficult and time-consuming task, so to study the problems of this research, finite element analysis using the ANSYS Workbench software package was used (Pham, D. Q. et al, 2023; Himmlová L. et al, 2004; Kopchak, A. V. & Kryschuk, M. G., 2014).

To compare the stress-strain states of the bone-implant system at different angles of implant placement, we selected the points of registration (Bida V. et al, 2018) of stress values (Fig. 3). The

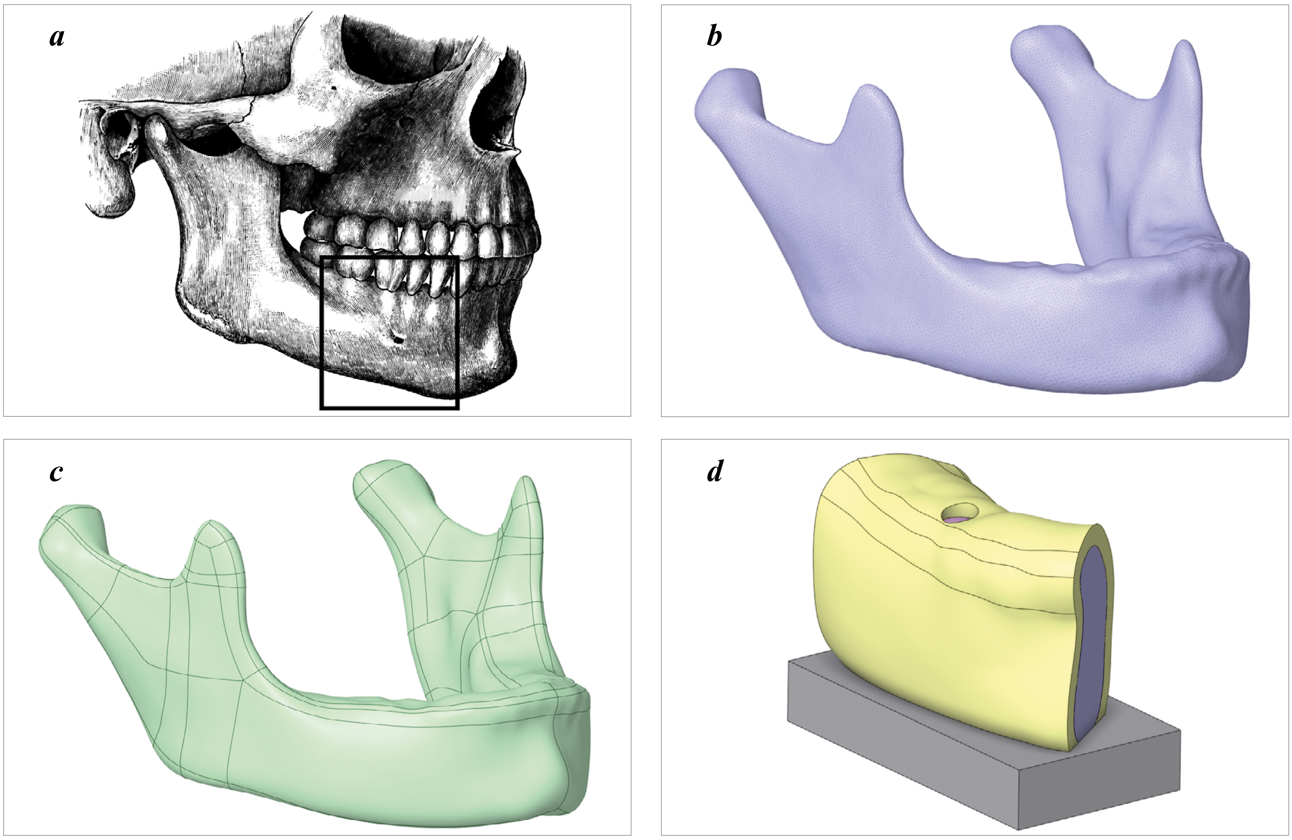


**Fig. 1.** (a) The area of the jaw under study; (b) Surface body; (c) Solid body; (d) Geometric model of the object of the research

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**Table 1.** Mechanical properties of materials of the design model

| Object | Material | E, GPa | μ | $\sigma_{crit}$, MPa |
|---|---|---|---|---|
| The outer layer of bone tissue | Cortical bone | 11 | 0,3 | 170-190 |
| The inner layer of bone tissue | Trabecular bone | 0,78 | 0,3 | 5 |
| The implant | Titan alloy Ti-6Al-4V | 111,2 | 0,3387 | 918 |
| The platform | Construction steel | 200 | 0,3 | 215 |

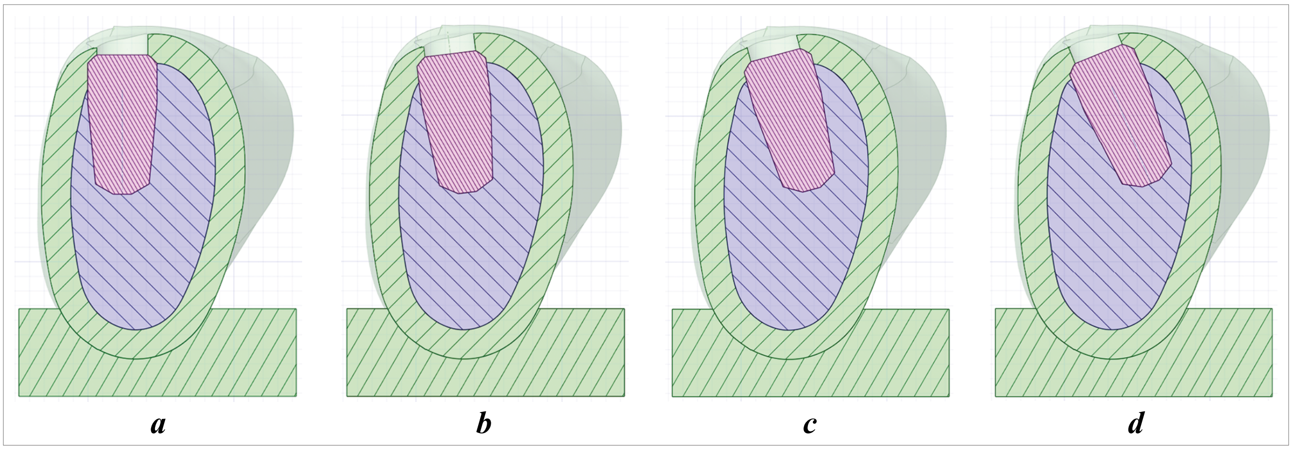


**Fig. 2.** (a) Implant positioned axially; (b) Implant positioned at an angle of $7^{o}$; Implant positioned at an angle of $15^{o}$; Implant positioned at an angle of $22^{o}$

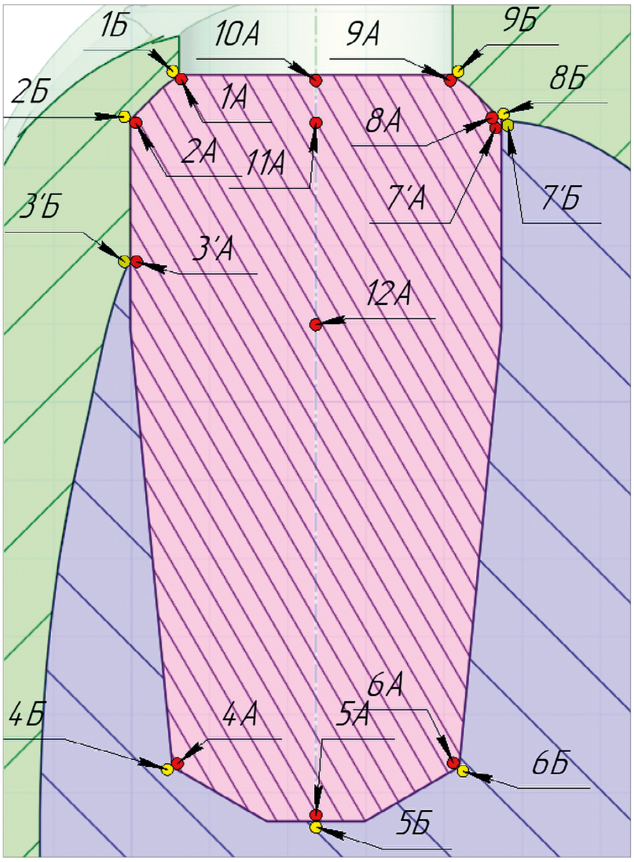


**Fig. 3.** Points of registration of stress values in the model

index "A" means that the point is in the implant, the index "Б" means that the point is in the bone tissue, and the index " ' " means that the point is at the border of the cortical and cancellous bone.

**Boundary conditions**

To prevent the displacement of the bone-implant system, the lower face of the platform was fixed and a vertical force of 200 N was applied to the upper face of the implant. Taking into consideration the specifics of the interaction between the model parts, the contacts were set to be bonded.

**Analysis of the results**

After calculation, the stress distribution in the bone-implant system was determined (Fig. 4).

The stress values for the four variants of implant placement at the considered points (Fig.3) are presented in Table 2.

The analysis of the calculation results indicates an uneven distribution of stresses in the system. The highest stress values are observed in the implant, while the lowest are in the trabecular bone tissue. It was determined that the maximum stresses in the system increase with an increasing angle of inclination of the implant, and these values remain

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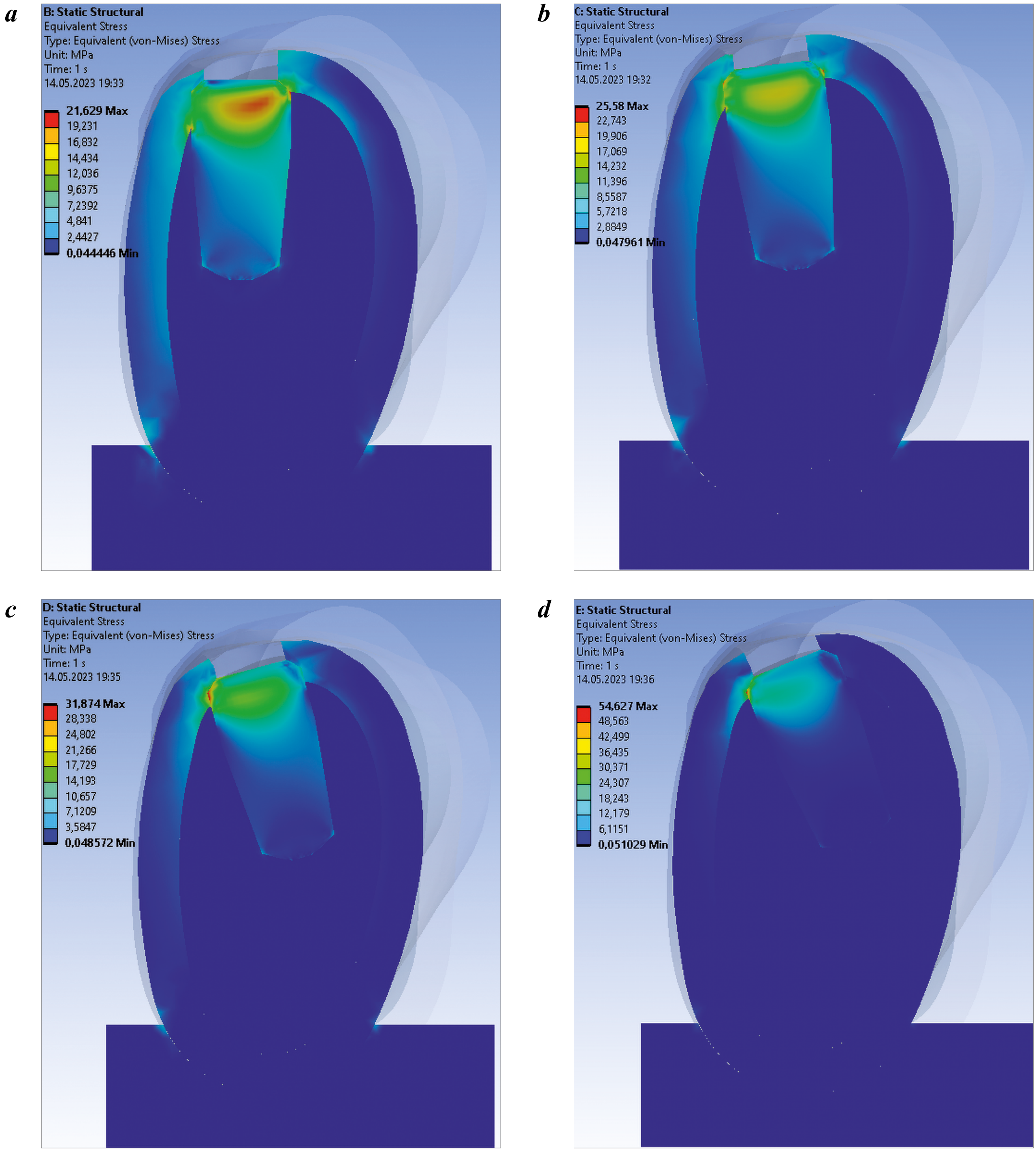


**Fig. 4.** Stress-strain state of the model with the implant placed: (a) axially; (b) at an angle of 7$^o$; (c) at an angle of 15$^o$; (d) at an angle of 22$^o$

less than the fracture strength of the materials (for titanium σmax = 54.36 MPa, for cortical bone tissue σmax = 30.37 MPa and for cancellous bone tissue σmax = 3.5 MPa).

In the course of the study, equations were obtained that reflect the dependence of the equivalent stress on the angle of inclination of the implant at the characteristic points of cortical and trabecular bone tissue (Fig. 5). Each of the equations has a high level of approximation reliability ($R^2 > 0.88$). The specific equations are as follows:

For point 2B: y = 0.019x^2 + 0.5331x + 9.1156, where x – is the implant angle and y – is the equivalent stress, with $R^2 = 0.998$.

**Table 2.** Stresses at the considered points

| Point № | Implant placement | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Axially | | 7° | | 15° | | 22° | |
| | A, MPa | B, MPa | A, MPa | B, MPa | A, MPa | B, MPa | A, MPa | B, MPa |
| 1 | 9,6156 | 6,0549 | 18,425 | 8,0188 | 19,721 | 13,996 | 23,732 | 20,589 |
| 2 | 14,807 | 8,9418 | 23,138 | 14,257 | 30,442 | 20,912 | 54,361 | 30,22 |
| 3’ | 20,274 | 17,117 | 21,713 | 18,584 | 24,272 | 21,466 | 40,5 | 30,37 |
| 4 | 6,5947 | 2,9321 | 8,641 | 2,8039 | 7,6119 | 3,2553 | 7,9962 | 3,4456 |
| 5 | 3,5213 | 0,9 | 3,3459 | 0,875 | 3,2371 | 0,8346 | 3,045 | 0,811 |
| 6 | 10,222 | 3,5012 | 7,4617 | 3,3478 | 7,9868 | 3,0143 | 6,5372 | 2,7986 |
| 7’ | 21,628 | 14,15 | 14,442 | 11,164 | 7,9419 | 7,0324 | 5,2006 | 5,6775 |
| 8 | 21,628 | 14,177 | 25,58 | 12,647 | 11,475 | 8,7521 | 11,179 | 5,0351 |
| 9 | 13,716 | 9,1337 | 18,142 | 5,9598 | 11,36 | 4,3272 | 13,102 | 1,973 |
| 10 | 5,4177 | - | 7,7565 | - | 11,742 | - | 15,278 | - |
| 11 | 12,622 | - | 12,501 | - | 12,879 | - | 13,601 | - |
| 12 | 8,3326 | - | 8,7063 | - | 8,516 | - | 8,2932 | - |

For point 8B: y = -0.0104x^2 - 0.1948x + 14.269, with $R^2 = 0.9972$.

For point 4B: y = 0.0015x^2 - 0.0062x + 2.8896, with $R^2 = 0.8806$.

For point 6B: y = -0.0003x^2 - 0.0265x + 3.5137, with $R^2 = 0.9911$.

**Conclusion**

As a result of the research, the stress distribution fields in the bone-implant system were determined and the maximum stress values at different angles of implant placement were determined. The dependence of the stresses on the angle of the implant was established.

An important result is that the maximum stresses that occurred in the system under a single static load do not exceed the limits, however, under cyclic loads they can be critical, which makes it important to conduct further research on this topic.

Thus, the obtained research results are important in planning an implant-supported orthopedic structure, namely in choosing the optimal installation angle, which in turn will ensure maximum duration and stability of dental implants in the oral cavity of patients. This is of great practical importance for dental practice and contributes to the improvement of orthopedic treatment of dentition

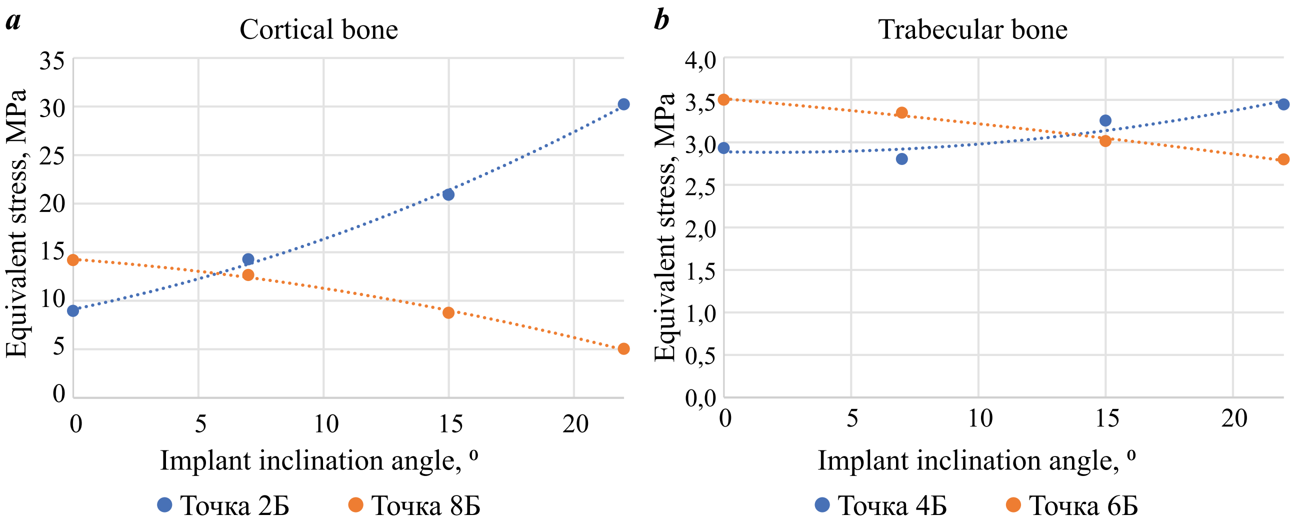


**Fig. 5.** Dependence of the equivalent stress at the considered points on the angle of inclination of the implant

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defects replaced by fixed dentures supported by implants. The use of this data in implant planning will help optimize the prosthetic process and ensure the proper functioning of dental implants, providing patients with a healthy and comfortable bite and aesthetic appearance.

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**Conflict of interests**

There are no conflicts of interests.

**Consent to publication**

All authors have read the text of the article and gave consent to its publication.

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## Вплив кута встановлення дентальних імплантатів на напружено-деформований стан щелепи

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***Анотація:*** *протезування на дентальних імплантатах є складним та відповідальним етапом лікування пацієнтів з дефектами зубних рядів. Успіх дентальної імплантації залежить не лише від ретельного планування та проведеного хірургічного втручання із дотриманням вимог протоколу, але й від виду навантаження на дентальний імплантат, вибору ортопедичної конструкції та матеріалу. Ґрунтовна підготовка до проведення протезування із врахуванням вихідної клінічної ситуації та індивідуальних особливостей пацієнта забезпечує повноцінне відновлення дефекту зубного ряду із відтворенням функції жування. Параметри напружено-деформованого стану в кістковій тканині навколо дентальних імплантів мають найважливіше значення для ефективності протезування на імплантах, особливо у віддалені терміни їх функціонування. Значні силові навантаження змінної амплітуди в щелепі призводять до резорбції кісткової тканини і неспроможності імплантатів бути опорою для зубних протезів. У зв'язку з цим актуальні дослідження по моделюванню напружено-деформованого стану в кістковій тканині при різних умовах навантаження імплантатів. В даній роботі отримані результати дослідження напружено-деформованого стану системи кістка-імплантат при статичному навантаженні. Проведено чисельні розрахунки для чотирьох кутів встановлення імплантату: 0°, 7°, 15° та 22°. Об'ємну модель частини нижньої щелепи та модель імплантату було зроблено в програмному забезпеченні Spaceclaim, а визначення напружень зроблено з використанням ANSYS Workbench. Одержані результати показують вплив кута встановлення імплантату на розподіл полів напружень в кістковій тканині та імплантаті. Аналіз результатів обчислень дозволить забезпечити оптимальне функціонування та довготривалість експлуатації дентальних імплантатів.*

**Ключові слова:** комп'ютерна симуляція; дентальні імпланти; дентальний аналіз напружень; метод скінченних елементів, щелепа, напруження.