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MATHEMATICAL ANALYSIS BASED STUDY OF DENTAL IMPLANT BIOMECHANICS WITH OCCLUSAL LOAD ON BONE TISSUE

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ABSTRACT — The article contains theoretical studies aimed at identifying the load and detecting the factors that have a negative impact on implants. One of the reasons behind implant disintegration is bone tissue resorption, which is due to overload. Direct measurements of the oral cavity stresses affecting the tissues around the implants are basically impossible. The purpose here is to choose the optimal inclination of the implant in relation to the vertical axis in view of mismatch of the mandibular and maxillary alveolar arches. The study here employed the finite element method (FEM) relying on the universal FEM ANSYS package. Three patterns have been identified. First, the dependence of the destructive force on the bone tissue on the implant inclination angle (up to 5° — it is twice as low compared to the initial value, and above 20° — it becomes destructive). Second, the implant deviation in the transversal plane results in a greater decrease in strength, compared to its deviation in the sagittal plane. Third, the greatest destruction resulting from the stress-strain bone tissue status is observed in the cortical, and not in the spongy bone. The study allows proper selection of implants, their installation options, as well as scientifically reliable forecast of the respective long-term outcomes.

KEYWORDS — mathematical analysis, implantation, biomechanics of implant.

INTRODUCTION

Despite the current progress in the modern dentistry, the number of patients with complete adentia has not revealed any decrease [1, 6–8]. A number of patients who use full removable dentures complain of poor fixation. This makes them apply for dental implantation in order to replace removable orthopedic dentures with non-removable ones. In case of significant atrophy of the alveolar processes in the upper and lower jaws, the inter-jaw ratios change. Given a mismatch, when the lower jaw alveolar arch is narrower than that of the upper jaw, the need arises to have implants installed on the lower jaw with a certain decline. Here, certain mechanical deformations occur both in the surrounding tissues and in the implant itself.

In case of a reasonable rational functional load, the endossal implant will stimulate osteogenesis after its introduction into the jaw bone through surgery. An increased occlusal load, which is not balanced in its strength, also being improper in its direction, will result in destroyed bone tissue at the respective area, as well as in the implant rejection. Given that, we are still facing the issue of objective evaluation of the bone tissue status at the periimplant zone thus aiming to prevent and treat pathologies affecting it.

The conducted studies allow, in each case, explaining and setting match as per each prosthetics scheme based on implants, with designing a proper mathematical model, including for situations of various prosthetic levels: in cases where several teeth are missing in a row with several free-standing implants to be installed, to cases of complete adentia where prosthetic bridges are to be installed relying on implants.

A high occlusive load is known to be one of the main reasons behind the implant disintegration. Rehabilitation to be offered to such patients appears a relevant issue that would enjoy a lot of demand. This scientific problem can be solved involving theoretical research in the field of mechanics of deformable bodies and structures. Given the advanced orthopedic treatment technologies relying on implants, it will take new mathematical approaches to make respective calculations, ensure the implant stability, as well as the strength of dentures.

Aim: to study dental implant of biomechanics in the lower jaw involving bone tissue, in view of occlusal load, involving mathematical analysis.

MATERIALS AND METHODS

The study was carried out employing the finite element method (FEM), which is currently the main calculation tool when it comes to studying the strength of various structures [2–5]. During that, the universal FEM ANSYS package was used.

The study involved the method of calculating bone tissue stresses under various loads on the implant, with a mathematical model for calculating the stress-strain status of the mandibular bone tissue designed, which was done subject to the generally accepted method. To identify the maximum loads that the implant works on the bone tissue, a volumetric model of the lower jaw was taken. The initial data were accepted as follows: the implant (titanium) — diameter D = 3 mm; elasticity modulus $E = 1.1 \cdot 10^5$ MPa; Poisson ratio $\mu = 0.3$. Cortical bone tissue: $E = 1.35 \cdot 10^4$ MPa; $\mu = 0.3$; tensile strength qcort = 40 MPa. Spongy bone: $E = 1.35 \cdot 10^3$ MPa; $\mu = 0.3$; qlip = 20 MPa. In order to idealize the implant-bone system, isoparametric volumetric elements of a second-order tetrahedral shape with ten nodes (SOLID92) were used. The analysis of the stress-strain status, which corresponds to the specified scheme of the implant loading, allowed identifying 6 main internal decisive force factors: stress along the implant (vertical load); stress in the sagittal plane (horizontal load); stress in the transversal plane (horizontal load); stress from the bending moment in the sagittal plane, respectively; stress from the bending moment in the transversal plane, respectively; stress from the torque.

RESULTS AND DISCUSSION

Nowadays, various prosthetics techniques involving the installation of dentures on implants are associated with bone resorption in the upper and lower jaw structures. A specific feature of resorption is the individual nature of load perception revealed by each patient, while it all depends on the type of the prosthetic biomechanical structures on implants.

Research focused on the stress-strain status shows that the destructive force is defined here as the lowest load at which equivalent stresses affecting the bone tissue reach the strength limit. The conducted studies allow, in each case, explaining and setting match as per each prosthetics scheme based on implants, with designing a proper mathematical model, including for situations of various prosthetic levels: in cases where several teeth are missing in a row with several free-standing implants to be installed, to cases of complete adentia where prosthetic bridges are to be installed relying on implants.

The mathematical analysis revealed that in case the implant deviation angle is 0°, there is only compression stress that occurs in the bone. It has no negative effect on the periimplant area tissues. When the implant deviates from the vertical axis, there is an additional bending moment that occurs at the spot where the implant is planted in the bone, i.e., the cervical area. The amount of additional stresses affecting the bone features a linear increase along with an increase in the implant inclination angle. The calculations allowed identifying the following pattern: in case there was no implant deviation from the vertical, the implant could resist a vertical load of 200 N, while at an implant inclination angle of 5°, it would go down to 100 N (half the initial value); when the angle is 10° only 72.5 N could be resisted, i.e., the destructive vertical forces went on increasing. In case of an inclination ranging within 10°-20°, the bone strength limit decreases proportionately to the increase in the implant inclination angle.

Beyond 20°, the tensile strength drops sharply, the implant being able to cope with a load of no more than 40 N. the degree of biomechanical risk, therefore, increases dramatically once the implant is tilted more than 10°, whereas after 20° it becomes destructive. The results of the calculations revealed another pattern. Comparing the implant inclination degree in the sagittal and transversal planes, reliable data were obtained showing that the implant deviation in the transversal plane will lead to a slightly greater decrease in strength than the deviation in the sagittal plane. (Fig.1, 2)

Moreover, the use of prostheses can lead, over time, to changes affecting the soft and bone tissue of the jaw supporting arches, which is due to the effect of loads from implants, also depending on the type of structures installed on them.

When the implant is tilted in the transversal plane, therefore, the degree of biomechanical risk is higher. In these cases, we would recommend plastic surgery of the alveolar process in order to increase it, so that further on the implant inclination degree could be reduced. Besides, there is certain interest in a comparative evaluation of the stress-strain status in the cortical and spongy bone.

We took the initial value of the most commonly seen implant inclination angle as equal to 10°. In case of the vertical force of 72.5 N applied in the transversal plane at the point where the implant contacts the cortical bone tissue, the stress is found to reach a strength limit of 40 MPa. The stresses in the spongy bone, however, are significantly below the destructive ones (20 MPa). A similar pattern was to be observed for the implant deviation in the longitudinal plane by an angle of 10°. The permissible destructive force, though, was slightly above in this case — 81.8 N in the cortical bone, while in the spongy bone it was 2 times as low. This means that there was a third pattern identified: the greatest destruction caused by the bone tissue stress-strain status in case of a deviated implant is to be observed in the cortical, and not in the spongy bone. This is in line with the clinical image of dental peri-implantitis obtained while following the respective dynamics. Bone resorption was found to begin in the cervical area of the installed implant. The overload first results in bone resorption with no inflammatory reaction reported, with a bone pocket developing, and then that is accompanied by the adjacent gum atrophy.

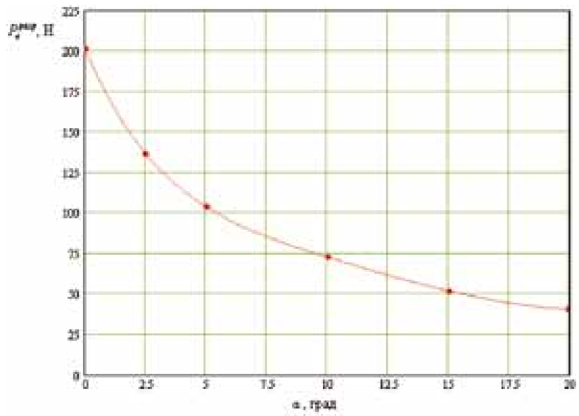

Fig. 1. Dependence of the vertical destructive force on the implant deviation angle in the transverse plane

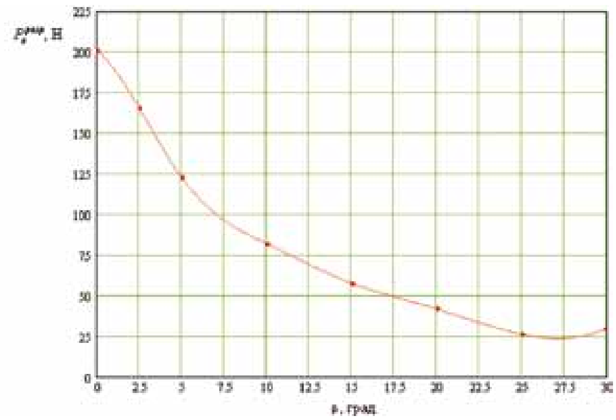

Fig. 2. Dependence of the vertical destructive force on the implant deviation angle in the longitudinal plane

Further on, along with an increase in the load, the bone tissue destruction increases, the entire process progresses, with inflammation joining it.

The developed methodology employed for mathematical modeling and investigation of the bone tissue stress-strain status will allow forecasting the likelihood of bone resorption in the real time mode as well as for future periods, depending on the implant design and on the types of their installation when subjected to average loads.

CONCLUSION

The mathematical analysis method employed for the implant-bone system allowed identifying the dependence of the effect that the implant inclination angle has on the bone tissue stress-strain status. The degree of biomechanical risk increases dramatically once the implant deviates more than 10°, whereas in the event the angle goes above 20°, the effect becomes destructive. Besides, the implant deviation in the transversal plane leads to a greater decrease in strength than sagittal deviation, wile the greatest damage in case of a deviated implant is to be seen in the cortical and not in the spongy bone.

The modeling and research methods allow, beyond other, predicting possible injury to soft and bone tissues due to a mathematically designed calculation of both the number of implants to be installed and their size and structure. The proposed methods and theory employed to study the effect that implant load will have on soft and bone tissues based on mathematical modeling will serve the basis for further progress of methodologies of explanation and implantation in two stages, or, in some cases, offering the possibility of one-stage implantation.

This means that a clear understanding of the implant biomechanics would allow improving treatment scheme for each patient thus aiming to reduce the risk of functional issues as well as the implant failure.

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