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COMPARATIVE STATIC STRENGTH EVALUATION OF THE IMPLANT–ABUTMENT JOINTS IN DIFFERENT IMPLANT DESIGNS

A. A. Elkanov, A. A. Dolgalev, Y. A. Sergeev, V. M. Avanisyan

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SUMMARY

Nowadays the problem of optimal restorative prosthetics on dental implants is of paramount importance for solving a number of clinically difficult cases and extends beyond the alternative treatment at the complete and partial adentia both on the upper and lower jaws. An essential factor here is understanding of the biomechanical behaviour of the implant-abutment interface, because an optimal implant-abutment interface simulates the biophysical behaviour of natural teeth and ensures the long-term function of the prosthetic restoration. The optimal method for assessing the implant-abutment junction is the static tensile strength method. The limit is determined by performing a single loading of the dental implant in the implant-abutment area.

The aim *of the study was to assess the implant-abutment deformation of demountable and non-demountable structures of the 4x10 cylindrical and cone-shaped dental implants with determination of their static strength limit.*

Materials and methods. *Two brands of dental implants have been chosen as the objects of research – cylindrical implant LIKO M 4x10 and cone-shaped implant LIKO M DG 4x10. A subject of the research is the ultimate strength of the implant-abutment unit of demountable and non-demountable abutment design.*

Results. *Static loading tests with estimation of the deformation limit of the implant-abutment unit were carried out along with the comparative estimation of the strength of demountable and non-demountable abutment constructions of dental implants of various shapes.*

Conclusion. *The carried out comparative analysis of the static strength makes it possible to optimise the process of prosthodontic treatment on dental implants taking into account the maximal limits of the loaded structures and to carry out the equilibrium load distribution.*

KEYWORDS: *dental implant, abutment, static testing, conical dental implant, cylindrical dental implant, implant-abutment unit.*

CONFLICT OF INTEREST. *The authors declare no conflict of interest.*

Funding. *Funding for the study was carried out from the personal funds of the authors.*

Introduction

Today, the issue of optimal restorative prosthetics on dental implants is of paramount importance in a number of clinically challenging cases and goes beyond alternative treatment for complete and partial adentia on both the upper and lower jaw. Understanding the biomechanical behaviour at the implant-abutment interface is essential, because an optimal implant-abutment interface mimics the biophysical behaviour of natural teeth and ensures the long-term function of the prosthetic restoration [3]. The optimal method for evaluating the implant-abutment junction is the static method for determining the strength limit [4–6]. The limit is determined by a single loading of the dental implant in the implant-abutment area [7–11].

The aim of the study was to assess the implant-abutment deformation of demountable and non-demountable abutment structures of 4x10 cylindrical and cone-shaped dental implants, with determination of their static strength limit.

Materials and research methods

Implementation of the implant-abutment unit strength limit by the level of the beginning of deformation was carried out in accordance with the protocol of strength tests of dental implants according to GOST R ISO 14801–2012 «Dentistry. Implants. Fatigue tests for intraosseous dental implants». [1, 2].

Demountable and non-demountable abutment structures with Lico-M and Lico-M DG 4x10 dental implants were chosen as objects of study for static tests of the implant-abutment unit (*Fig. 1*). The abutment was fixed with a torque wrench at 25 N*cm, taking into consideration the pre-tightening of the screw.

The static strength was assessed under single loading without consideration of load asymmetry. The abutment

A B

Fig. 1: Demountable and non-demountable abutment design: A) cylindrical abutments, B) conical abutments

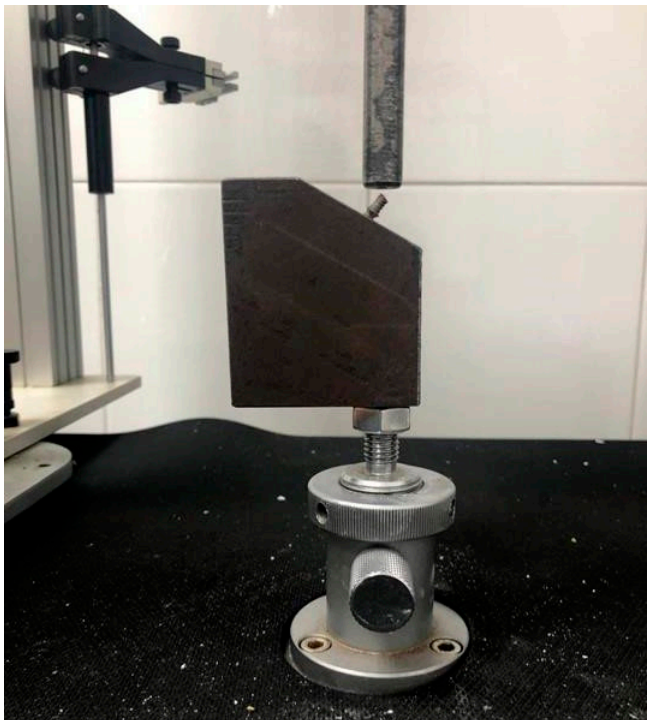

Fig. 2: Holder with fixed implant.

Table 1

Static test results of the implant-abutment connection.

No. n/a	d, mm	Sample No.	F max, N	Place of destruction
1.	4,0	1	698	screw
2	4.0	2	696	screw
3	4.0	3	642	screw
4	4,0	4	631	screw
5	4,0	5	657	screw
6	4.0	6	682	screw
7	4.0	7	858	Abutment
8	4,0	8	962	Abutment
9	4.0	9	1150	Abutment
10	4.0	10	1042	Abutment
11	4,0	11	978	Abutment
12	4,0	12	996	Abutment

and implant were fixed in the holder with a photopolymerizable composite to match the axis of force application (*Fig. 2*). The load was applied by means of a flat loading device to a hemispherical element secured to the abutment with a screw.

The static strength of the implant-abutment connection was determined using the Gotech-AI7000S testing machine (*Fig. 3*).

Results

The results were determined based on the initial structural displacement under static loading in order to determine the limits of the implant-abutment assembly (*Table 1*).

Based on the static strength analysis of the implant-abutment connection, the static strength results of the non- demountable constructions were optimal, as the average strength values were 997 N compared to the demountable ones, 668 N (*Fig. 4*).

Fig. 3: GT-AI7000-S test machine.

In a comparative assessment of the dependence of implant-abutment margins on the shape of the dental implant, a correlation was established between non-displaced structures fixed on cone and cylindrical implants, with a mean value of 643 N for cone and 692 N for cylindrical implants (*Fig.* 5).

The values for the demountable abutment designs were similarly compared. For cone abutments, these values averaged 932.7N, and for cylindrical abutments, 1062.7N, reflecting the dependence of the limit values of the implant-abutment assembly on the shape of the dental implant.

Conclusions

In determining the implant-abutment connection limits among demountable and non-demountable abutment designs, it was found that the optimally high values were characteristic of the non-demountable designs. At the same time, the dependence of the implant-abutment strength on the shape of the dental implant was found to be lower for cone-shaped dental implants, both for demountable and non- demountable designs.

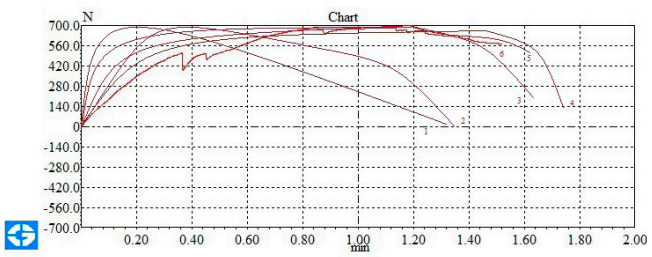

Fig. 4. Static test schedule for specimens with demountable abutment design

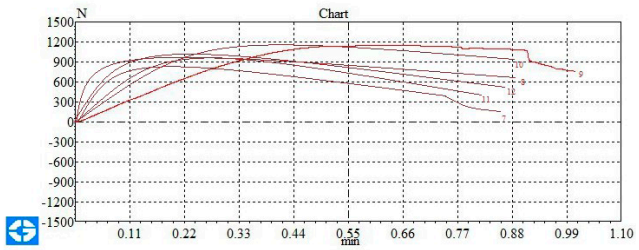

Fig. 5. Static test schedule for specimens with non-disassembled abutment design

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REAL–TIME POLYMERASE CHAIN REACTION (PCR) APPLICATION FOR THE DETECTION OF PERIODONTOPATOGENS

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SUMMARY
The ethiological factor of periodontal diseases is the presence of periodontopathogens; in state of imbalance with commensals they begin to affect pathologically. With a decrease in the number of periodontopathogens in the biofilm, it is possible to restore the balance and prevent periodontal diseases or their transition to the stage of remission. Nowadays, the most informative and accessible diagnostic method for determining periodontopathogens is real-time polymerase chain reaction (PCR).

KEYWORDS: *periodontitis, periodontopathogens, polymerase chain reaction (PCR), periodontium, prevention.*

CONFLICT OF INTEREST. *The authors declare no conflict of interest.*

Relevance

Periodontitis is a chronic inflammatory disease of the gums of polymicrobial etiology. Porphyromonas gingivalis, Tannerella forsythia and Treponema denticola are directly associated with this disease and are therefore called periodontopathogens or red complex bacteria [14.15]. These gram-negative obligate anaerobic bacteria exist in the biofilm that forms in subgingival pockets, and Fusobacterium nucleatum serves as a bridge to the supragingival biofilm, which consists mainly of streptococci [16]. The lipopolysaccharide (LPS) of these bacteria acts as an immunostimulant, causing gingival inflammation and activating osteoclasts through Toll-like receptors (TLR 2 or TLR 4), which trigger the expression of various cytokines, which in turn causes alveolar bone resorption [14]. However, recent metagenomic studies indicate that a wide range of microbiota associated with periodontitis may be involved in the disease process, which has to be identified yet [4].

Traditional treatment of periodontitis involves a non-surgical treatment aimed at controlling the pathogenic plaque and calculus biofilm from the crown and root surface through mechanical procedures (scaling) combined with improved personal hygiene, thus reducing inflammation and pocket depth. [10, 19.] In severe cases, antibiotic therapy may be required to hasten resolution of the disease [5]. Such therapeutic approaches are not always associated with success, and the frequent recolonization of treated areas with periodontal pathogens, as well as the emergence of antibiotic resistance, have led to the need to search for new therapeutic approaches for the treatment of periodontal diseases [3].

Among the various procedures used to detect oral bacteria, such as microbial culture, immunological assays, enzymatic methods, and molecular biology, the polymerase chain reaction (PCR) diagnostic method has become a powerful and increasingly popular tool due to its speed, sensitivity, and efficiency [12].

A number of methods have been developed for the detection and quantification of periodontal pathogens, including bacterial cultures, flow cytometry, DNA-DNA hybridization, immunoassays, enzymatic methods, and standard polymerase chain reaction (PCR). However, most of these methods are labor intensive and time consuming. In addition, they all have their own subjective limitations to achieve the desired sensitivity and specificity for accurate quantification of specific bacteria in samples [7, 13]. In recent years, quantitative real-time PCR technology has been developed to quantify bacteria. Real-time PCR with species-specific primers overcomes the limitations of traditional methods and becomes more suitable for bacterial quantification [1, 2, 6, 8, 9, 11, 19, 20, 21, 20]. Over the past 10 years attention has been drawn to the usage of saliva as a diagnostic fluid for periodontal disease [17].

Materials and methods

The survey included 20 patients: 10 men and 10 women who applied to North Caucasus Medical Training Centre LTD.

All patients completed a General and Disease History Questionnaire, Bleeding on probing (BoP), Probing Depth (PD), and Clinical Attachment Loss (CAL) and Plaque Index (PI), and a– radiological bone loss (RBL). The criteria for inclusion of patients in the experimental group was the diagnosis of moderate periodontitis (presence of BOP, PD – ≤ 5 mm, CAL – 3–4 mm, RBL – 15 % – 33 % PI – 1–3). No history of tooth loss due to periodontitis. The control group consisted of patients with healthy periodontal tissues (BOP – <10 %, PD – ≤ 3mm, CAL – no, RBL – no PI – 0–1)

The experimental group included 10 patients (5 men and 5 women) in the control group 10 (5 men and 5 women)

The material was taken in the morning, before the procedure of tooth brushing on an empty stomach. Previously, the tooth was dried with sterile gauze swabs. Samples were taken using

Table 1

Results of the examination of the control group of patients

No.	Sex	Age	Tooth	Actinobacillus actinomycetemcomitans (Lg)	Porphyromorans gingivalis (lg)	Prevotella intermedia (lg)	Tannerella forsythesis (lg)	Treponema denticola (lg)
	M	31	4.6				2.5	
	M	26	4.6					
	F	30	4.6				2.1	
	F	34	3.6		2.1	0.9	2.4	2.2
	F	28	3.6					
	M	27	3.6				2.1	
	F	30	4.6			2	2.9	
	M	24	4.6				2.6	1.6
	M	25	2.6				2.6	
	F	29	2.6				1.7	

Table 2

Results of the examination of the experimental group of patients

No.	Sex	Age	Zone	Actinobacillus actinomycetemcomitans (Lg)	Porphyromorans gingivalis (lg)	Prevotella intermedia (lg)	Tannerella forsythesis (lg)	Treponema denticola (lg)
	F	48	3.3		4.6	4.5	3.8	3.4
	M	60	4.6	2	5.3	4.2	3.8	4
	F	53	1.5		1.4			2.5
	M	61	3.6		4.5		3.4	2.6
	M	54	2.6		4.2			3.3
	F	64	4.4		2.5		0.8	
	M	61	2.5		5.2		4.3	4
	F	61	3.5		1.9			
	M	56	2.2		3.5	2.9	3.4	
	F	44	3.4		4.1	3.1	3.4	3.9

sterile paper endodontic pins of size No. 25, by immersion in the deepest periodontal pocket (patients of the experimental group) or in the gingival sulcus (patients of the control group) for 10 s. Then the paper point was removed and placed in a plastic test tube of the Eppendorf type with the DNA-Express. Detection of five periodontopathogenic microorganisms: Actinobacillus (Aggregatibacter) actinomycetemcomitans (Aa), Porphyromonas gingivalis (Pg), Prevotella intermedia (Pi), Tannerella forsythensis (Tf) and Treponema denticola (Td) was performed by quantitative PCR with real-time detection of results using Dentoscreen set.

Research results

Tannerella forsythensis was found in eight patients in the control group, Treponema denticola was found in 6 patients, which may indicate an increased risk of developing periodontal diseases. According to the literature, Tannerella forsythia and Treponema denticola are included in the «red complex» of periodontopathogens (Socransky et al., 1998). Bacteria included in this group prevent the colonisation of commensal bacteria and are considered the most pathogenic periodontal complex, found in significant numbers in active and progressive periodontitis (Thurnheer et al., 2014; Holt & Ebersole, 2005). The results of the control group are presented in *Table 1.*

In 100 % of patients of the experimental group, Porphyromorans gingivalis (42.9 %), Tannerella forsythensis (66.7 %) and Treponema denticola (33.3 %) are found mostly.

The most rarely detected Actinobacillus actinomycetemcomitans (4.8 %) and Prevotella intermedia (14.3 %). The results of the experimental group are presented in *Table 2.*

Conclusion

The results of the study provide an understanding of the qualitative and quantitative presence of periodontopathogens in individuals with moderate periodontitis, as well as in clinically healthy patients. Microorganisms are the etiological cause of inflammatory diseases of periodontal tissues, and their detection at an early or preclinical stage determines the success of treatment, allowing to reduce the microbial load. The PCR method is not widely used in clinical practice, although it has several advantages:

- control of the microbial landscape before treatment, as well as during the stages;
- prevention of periodontal disease at an objective level;
- earlier detection of periodontal disease.

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STATIC STRENGTH ESTIMATE OF STRUCTURAL ELEMENTS OF IMPLANT SYSTEMS LIKO 4 × 10 OF VARIOUS DESIGNS

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SUMMARY

Introduction. *The creation of effective, reliable, safe, technologically advanced and competitive products is the main task of medical device engineering. The most important requirement to modern medical devices is to guarantee patients' safety during their lifetime. Today the use of modern computer-aided engineering analysis packages is the most effective calculation method for evaluating the strength and reliability of unique medical devices that can lead to serious consequences if their operation is disturbed. One of the most suitable and efficient systems for computer-aided engineering (CAE) system is the ANSYS software.*

The purpose *of this study was the comparative assessment of the elastic and elastoplastic formation of 4x10 dental implants of different designs on the abutment-pin and screw-body interface, using the computer simulation of the stress-strain state.*

Materials and methods. *Two kinds of dental implants were chosen for this study: a Liko-M 4 × 10 implant with the cylindrical body shape and a Liko-M DG 4 × 10 implant with a tapered body shape. The contact between the abutment and screw as well as the implant body and screw is frictional. The pre-tensioning of the screw from the initial tightening was 400 N. The load was applied to the cylindrical surface of the abutment at a percentage of its height.*

Results. *Elastic and elasto-plastic calculations of the stress-strain state of Liko-M 4 × 10 and Liko-M DG 4 × 10 implants were performed. Besides the results of the main calculations of the stress-strain state of the implants Liko-M 4x10 and Liko-M DG 4 × 10, necessary to assess their static strength, we have also calculated the strength coefficients of implant bodies. Comparative analysis of the static strength of the Liko-M 4 × 10 and Liko-M DG 4 × 10 implants provides conclusions, which are significant for practical application of the implants.*

KEYWORDS: *strain calculation, stress-strain state, dental implants, static strength.*

CONFLICT OF INTEREST. *The authors declare no conflict of interest.*

Introduction

The creation of efficient, reliable, safe, technologically advanced and competitive products is a major challenge in the medical device industry. In addressing this challenge, there is an urgent need to improve the performance of manufactured products, improve the manufacturing process and reduce the time, cost of development, and testing. The most important requirement for modern medical devices is to guarantee patient safety throughout their lives. [1]

The use of modern computer-aided engineering analysis packages is by far the most effective calculation method for assessing the strength and reliability of unique medical devices, whose malfunction can have dire consequences. One of the most suitable and efficient systems for automated engineering calculations (CAE-system) is the ANSYS software which allows simulation of possible functional outcomes and probable failures of medical equipment and materials. [2–4]

The aim of this work was to compare the elastic and elastoplastic deformation of 4x10 dental implants of different design on the abutment-screw and screw-body interface using computer simulation of the stress-strain state (SSS).

Materials and methods

Two types of dental implants were chosen as an object of study: a Lico-M 4x10 implant with a cylindrical body shape and a Lico-M DG 4x10 implant with a tapered body shape; implant diagrams are shown in *Figures 1* and *2*.

The contact between the abutment and screw and the implant body and screw is frictional. It is this contact and the structural elements that form it that we investigated.

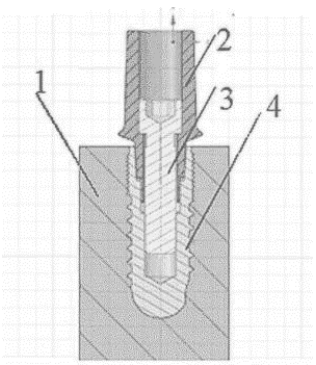

Fig. 1. Design of the Lico-M 4x10 dental implant: 1 – bone block, 2 – abutment, 3 – screw, 4 – implant body

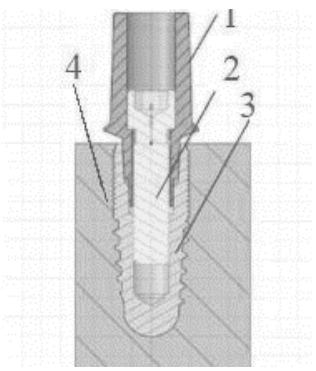

Fig. 2. Design of the Lico-M DG 4x10 dental implant: 1 – abutment, 2 – screw, 3 – implant body, 4 – bone block

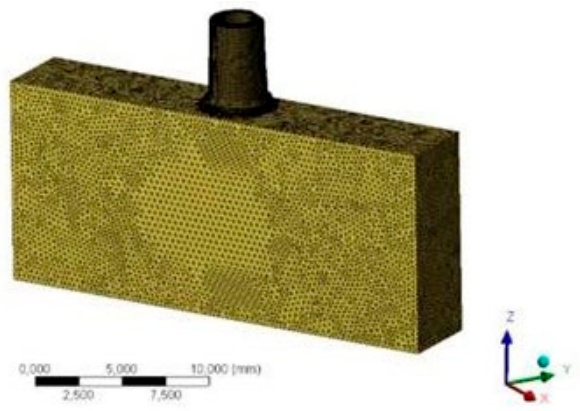

Fig. 3. Finite element grid of the Lico-M 4x10 implant

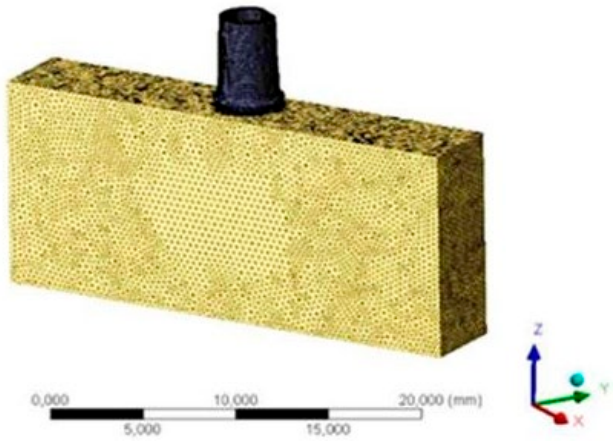

Fig. 4. Finite element grid of the Lico-M DG 4x10 implant

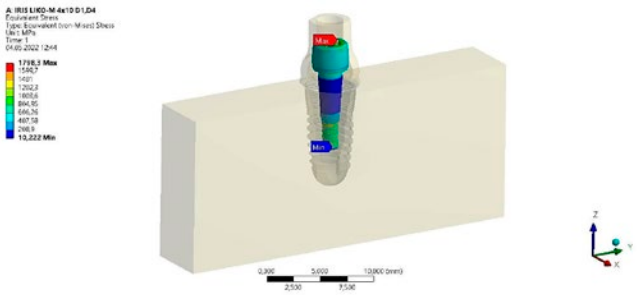

Fig. 5. Mises stress distribution of the Lico-M 4x10 dental implant screw *(time = 1 c)*

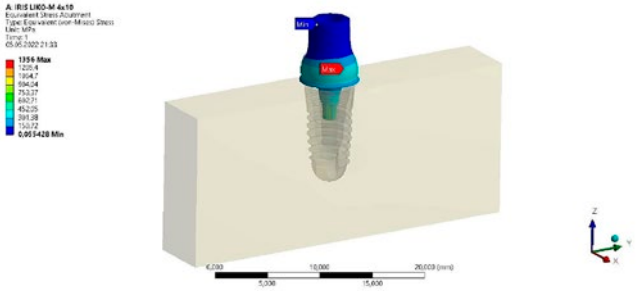

Fig.6. Distribution of Mises stresses in the abutment of a 4x10 Lico-M dental implant *(time* = 1 c)

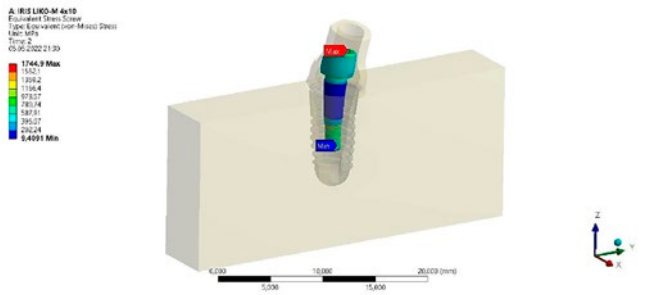

Fig.7. Mises stress distribution of the Lico-M 4x10 dental implant screw *(time = 2 c)*

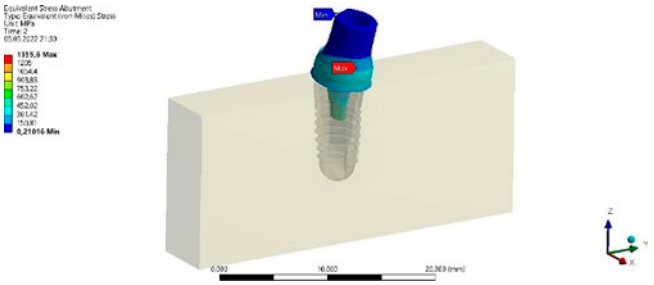

Fig.8. Distribution of Mises stresses in the abutment of a 4x10 Lico-M dental implant *(time* = 2 c)

The pre-tensioning of the screw from the initial tightening was 400 N. The load was applied to the forming cylindrical surface of the abutment by a percentage (%) of its height. It should be assumed that the load was directed downwards at an angle of 30° to the vertical in a plane perpendicular to the longitudinal vertical plane of the bone block.

The implant system parts, abutment and screw, are made of Grade 5 titanium alloy. Based on the studied dental implants, finite element meshes were created and used in further computer simulations, which are shown in *Figures 3* and *4*.

Results and conclusions

In the course of the work, calculations were carried out on the implants:

- elastic calculation of the Lico-M 4x10 dental implant; Lico-M DG 4 x10;
- elasto-plastic calculation of the Lico-M 4 × 10, Lico-M DG 4 × 10 dental implant.

Elastic calculation of Lico-M 4x10 and Lico-M DG 4 × 10 dental implants

Figures 5–8 show the distribution of the Mises stresses in the elements of the Lico-M 4x10 dental implant at the moments which correspond to the end of the screw pre-tightening process *(time = 1 c)* and the end of the loading process *(time = 2 c)*. *Figures 9–12* show the distribution of the reduced measure stresses in the elements of the Lico-M DG 4 × 10 dental implant at the similar moments of time. The results of the elastic calculation of the Lico-M 4 × 10 Lico-M DG 4 × 10 implant are shown in summary *Table 1*.

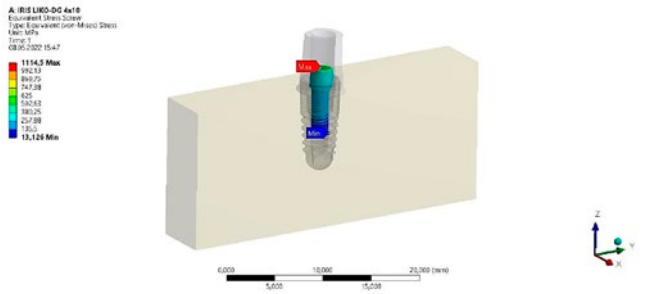

Fig.9. Distribution of Mises stresses in the screw of the Lico-M DG 4x10 dental implant *(time = 1 c)*

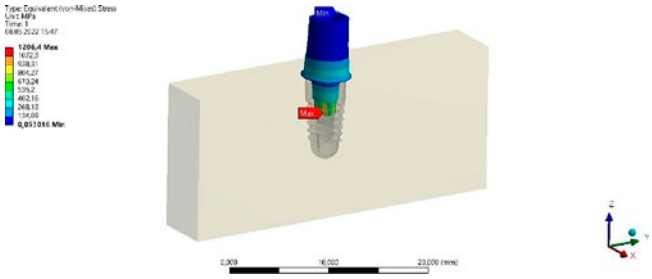

Fig.10. Distribution of Mises stresses in the abutment of the Lico-M DG 4x10 dental implant *(time = 1 c)*

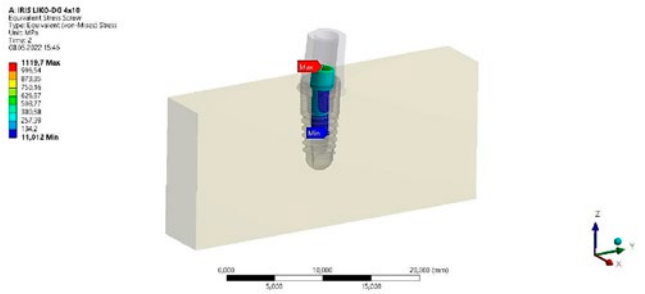

Fig.11. Mises stress distribution of the Lico-M DG 4x10 dental implant screw *(time =2 c)*

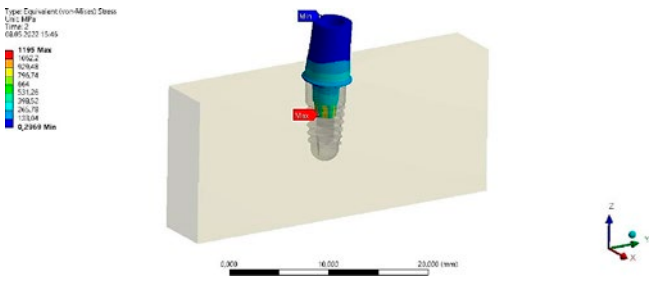

Fig.12. Distribution of Mises stresses in the abutment of a Lico-M DG 4x10 dental implant (time =2 c)

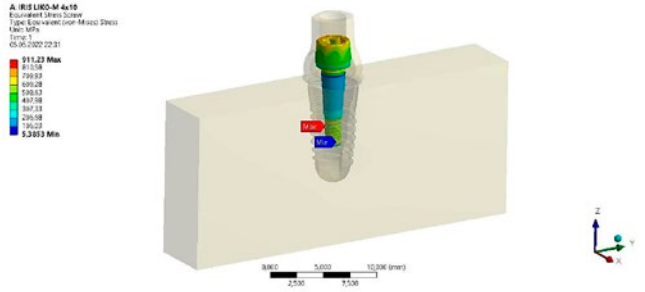

Fig.13. Mises stress distribution of the Lico-M 4x10 dental implant screw *(time = 1 c)*

Table 1

The results of the elastic calculation of the Lico-M 4x10 and Lico-M DG 4x10 implants.

Feature	Implant brand			
	Liko-M		Liko-M DG	
	time = 1s	time = 2s	time = 1s	time = 2s
Maximum value of Mises stresses in the screw, MPa	1798,3	1750	1114,5	1119,7
Maximum value of Mises stresses in abutment, MPa	1356	1355,6	1206,4	1195

Since the maximum Mises stresses in the screw and abutment exceed the yield strengths of the materials which they are made, an elasto-plastic calculation must be carried out.

Elasto-plastic calculation of Lico-M 4x10 and Lico-M DG 4x10 dental implants

Figures 13–16 show the distribution of the Mises stresses in the elements of the Lico-M 4x10 dental implant at the moments that correspond to the end of the pre-tightening process *(time = 1 c)* and to the end of the loading process *(time = 2 c)*.

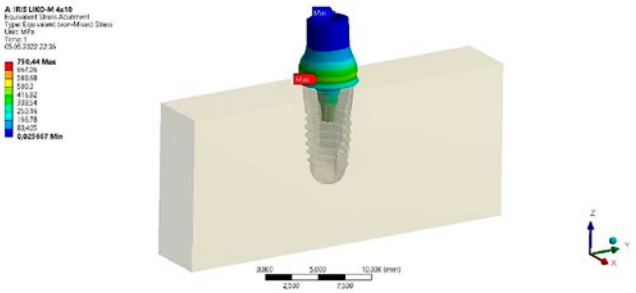

Fig.14. Distribution of Mises stresses in the abutment of a 4x10 Lico-M dental implant (time = 1 c)

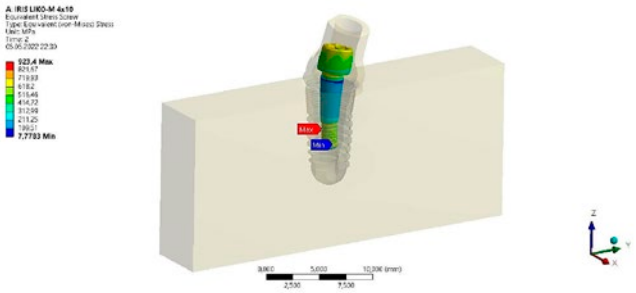

Fig.15. Mises stress distribution of the Lico-M 4x10 dental implant screw *(time = 2 c)*

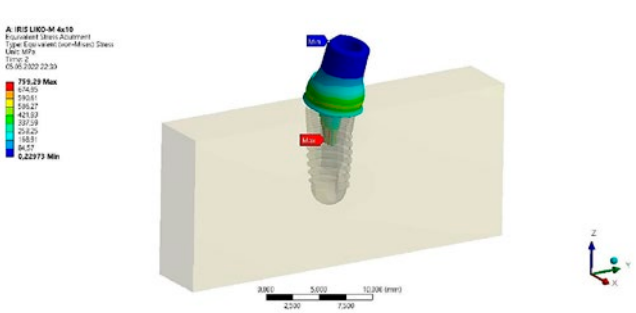

Fig. 16. Distribution of Mises stresses in the abutment of a 4x10 Lico-M dental implant (time = 2 c)

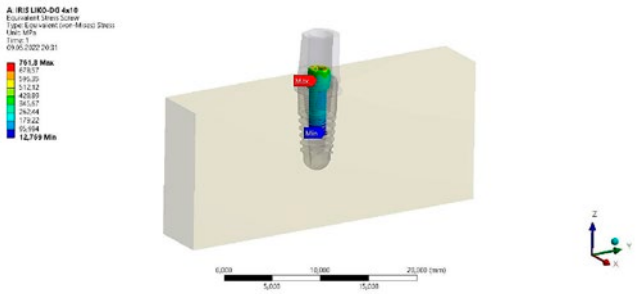

Fig. 17. Mises adjusted stress distribution of the Lico-M DG 4x10 dental implant screw (time = 1 c)

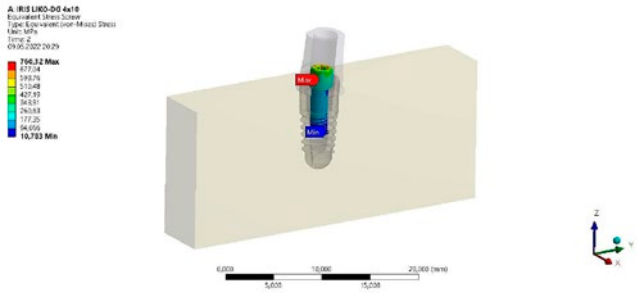

Fig.19. Mises stress distribution of the Lico-M DG 4x10 dental implant screw *(time =2 c)*

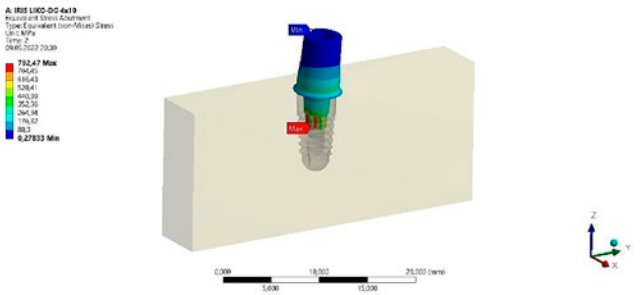

Fig.20. Distribution of Mises stresses in the abutment of a Lico-M DG 4x10 dental implant (time =2 c)

Figures 17–20 show the distribution of the reduced stresses in the elements of the Lico-M DG 4x10 dental implant at the similar moments of time. The results of the elasto-plastic calculation of the Lico-M 4x10 Lico-M DG 4 × 10 implant are shown in summary *Table 2.*

Table 2

The results of elasto-plastic calculation of Lico-M 4x10 and Lico-M DG 4x10 implants

Feature	Implant brand			
	Liko-M		Liko-M DG	
	time = 1s	time = 2s	time = 1s	time = 2s
Maximum value of Mises stresses in the screw, MPa	911,2	923,4	761,8	760,3
Maximum value of Mises stresses in abutment, MPa	750,4	759,3	787,7	792,5

The received quantitative data of the specified Mises stresses show that the Lico-M DG 4 × 10 implant has the 20% lower potential energy of the form changes and deformation as compared to the Lico-M 4 × 10 implant due to its cone-shaped body. These results are particularly important for clinical

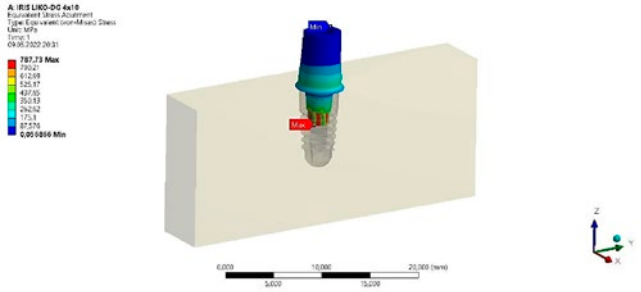

Fig.18. Distribution of Mises stresses in the abutment of a Lico-M DG 4x10 dental implant (time = 1 c)

use because they determine the choice of an implant system with the best technical characteristics and the least amount of bone deformation in the implant bed.

Besides the results of the main calculations of the stress-strain state of the implants of LicoM 4 × 10 and Lico-M DG 4x10 brands, necessary to assess their static strength, the strength coefficients of implant bodies were calculated. The numerical data are given in *Table 3.*

Table 3

Safety factors for implant bodies

Loading stage	Implant brand	
	Liko-M	Liko-M DG
Elastic calculation		
Screw pre-tightening (first stage of loading)	0,205	0,824
Load application (second stage of loading)	0,204	0,751
Elasto-plastic calculation		
Screw pre-tightening (first stage of loading)	0,287	0,801
Load application (second stage of loading)	0,287	0,782

Quantitative data on the safety margin of the implant bodies show that the Lico-M DG 4x10 implant is approximately four times stronger than the Lico-M 4x10 implant, which means a longer lasting use of this implant system without the possible early risk of screw breakage or implant replacement.

The relative reduced stresses of the implant bodies are calculated as inverse values to the values of safety factors. The calculated values of the relative reduced stresses of the implant bodies are shown in *Table 4.*

Table 4

Relative reduced stress of implant bodies

Loading stage	Implant brand	
	Liko-M	Liko-M DG
Elastic calculation		
Screw pre-tightening (first stage of loading)	4,88	1,21
Load application (second stage of loading)	4,9	1,33
Elasto-plastic calculation		
Screw pre-tightening (first stage of loading)	3,48	1,24
Load application (second stage of loading)	3,48	1,27

The obtained quantitative data of the relative reduced stresses of the implant bodies similarly indicate a lower application of forces for tightening the screw of the Lico-M DG 4x10 implant, which also influences its long-term clinical use without possible deformations of the implant body or screw breakage.

Conclusions

A comparative analysis of the static strength of the Lico-M 4x10 and Lico-M DG 4x10 implants has led to the following conclusions, significant for the practical use of the implants:

- the loading process of the implant is two-stage: the first stage is the pre-tightening of the screw and the second stage is the application of load;
- the loading level of the implant changes non-linearly during the loading process: a high loading level is formed in the first stage and redistribution of stresses occurs in the second stage;
- the distribution of stresses over the implant components is not uniform; the maximum values of the Mises stresses occur in the implant body at the point of contact of the implant body with the abutment;
- considering the high level of loading of the implant components under consideration, a possible way to increase their static strength is to reduce the pre-tightening value of the screws.
- comparing two implant systems in terms of physical-mechanical properties of their elements and static strength analysis, preference is given to the Lico-M DG 4x10 implants due to the peculiarities of their body design, lower screw tightening force application, lower Mises stress values in the screw, almost 20 % lower, and a higher safety factor in clinical use, which is confirmed by quantitative data.

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ELIMINATION OF THE DEFECT OF THE ALVEOLAR CEST WITH A VASCULARIZED PALATINE FLAP

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SUMMARY

Soft tissue augmentation is a narrow direction in the reconstruction of the jaw bones, the number of techniques increases every year, while the issues of integrating flaps outside the axial type of blood supply remain relevant [1, 2]. The development of a minimally invasive method with the creation of an optimal blood supply will allow recreating the architectonics of soft tissue structures for a stable result and the subsequent possibility of bone augmentation with extended mandibular defects. Target. Clinical approbation of a vascularized palatal mucoperiosteal flap to eliminate the defect of the alveolar ridge.

Materials and methods. *42 patients underwent defect repair using a vascularized mucoperiosteal flap and 31 patients using standard free flaps.*

Results and discussion. *In the early postoperative period on the 12th day the restoration of soft tissue structures in a volume of at least 2 cm², along the top of the alveolar ridge, a height of at least 16 mm, a thickness of at least 20 mm. One month after surgery, the height is not less than 15 mm, the thickness is not less than 20 mm, the volume is about 2 cm². By the end of the third month, the indicators remained stable and corresponded to the previous figures, which indicates the absence of a shrinkage mechanism and the stability of soft tissue structures. 31 patients who have previously undergone augmentation using free grafts note a significant difference in the volume of the intervention and note its effectiveness in comparison with the previous one.*

Conclusions. *The use of a vascularized palatal mucoperiosteal flap is justified by its incomparable capabilities. After it's taken, it is possible to restore soft tissues with an area of 3.5 cm² or more. The risk of postoperative shrinkage is minimal due to adequate blood supply. Identical morphological characteristics of the oral mucosa are fundamental in solving aesthetic issues in dental implantation.*

KEYWORDS: *vascularised flap, bone augmentation, dental implantation.*

CONFLICT OF INTEREST. *The authors declare no conflict of interest.*

Introduction

Restoration of functional balance in the dentoalveolar system often occurs through prosthetics on dental implants, the installation of which requires compliance with a number of conditions [2]. To achieve them, various methods of bone and soft tissue augmentation are being developed and implemented. They make it possible to obtain optimal parameters in the projection of the recipient bed [3, 4]. The current methods of reconstruction of soft tissue structures of the alveolar ridge fit into the framework of the use of free full-thickness and (or) split mucoperiosteal flaps [5–7]. A significant number of cases is characterized by an unsatisfactory result, which is due to a high degree of shrinkage, as well as an insufficient volume of donor structures [8]. Existing techniques for the collection and transposition of a vascularized palatine autograft are used to eliminate dentoalveolar anomalies and recreate the volume of soft tissue structures in the lateral segment of the upper jaw. The use of this flap to compensate for a defect in the alveolar ridge is a laborious process, at the same time, according to a number of researchers, its morphological and functional capabilities are characterized as the most optimal for eliminating soft tissue defects covering the alveolar ridge [9,10].

The purpose of the study

Clinical approbation of a vascularized palatal mucoperiosteal flap for elimination the defect of the alveolar ridge.

Materials and methods

From 2019 to 2023, 42 patients were operated in State Budgetary Health Institution of the Stavropol Territory

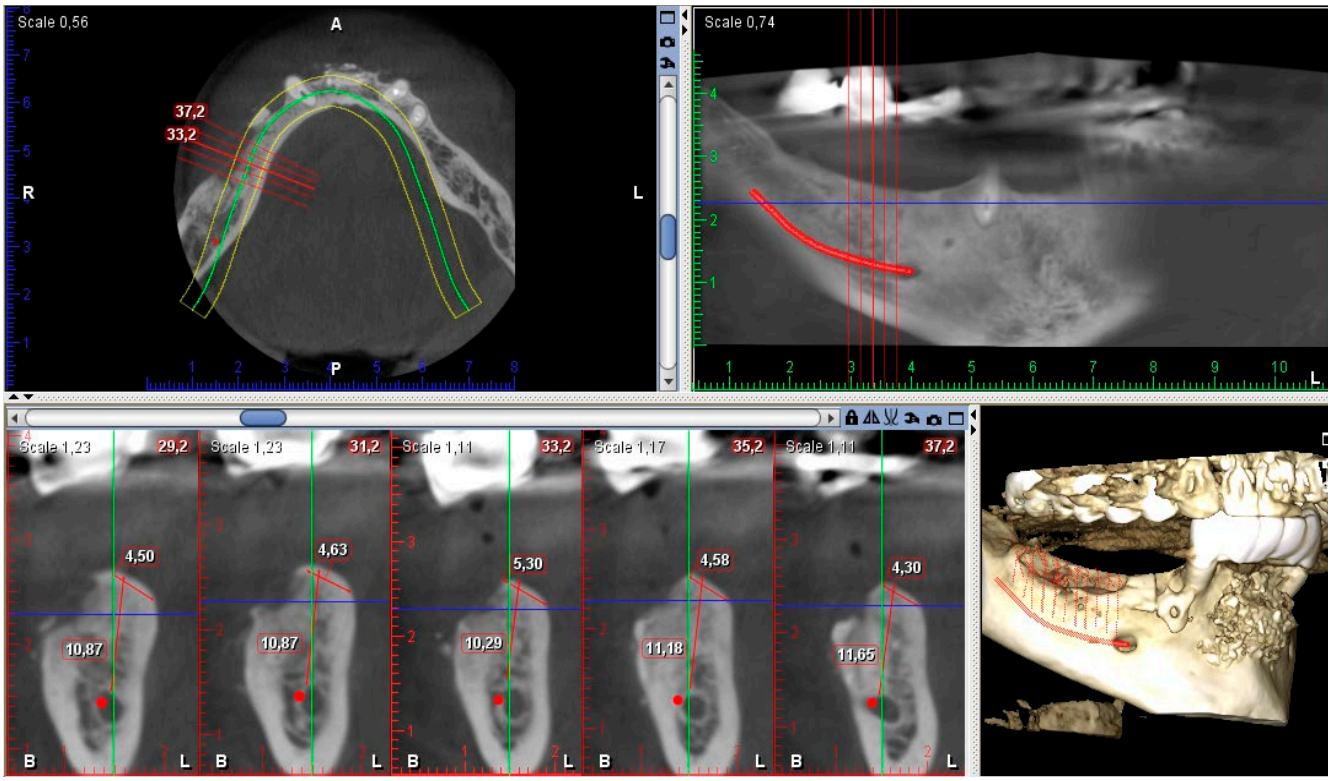

Fig. 1. Patient S., 54 years old, state after repeated osteoplastic surgeries, the Kennedy second class

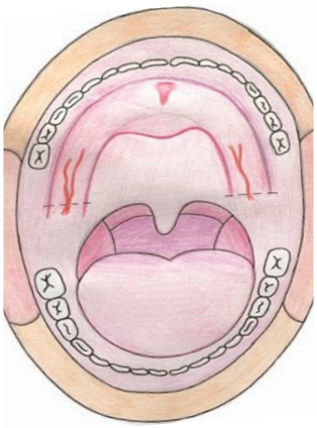

Fig. 2. Schematic representation of the incision design when modeling the tested flap

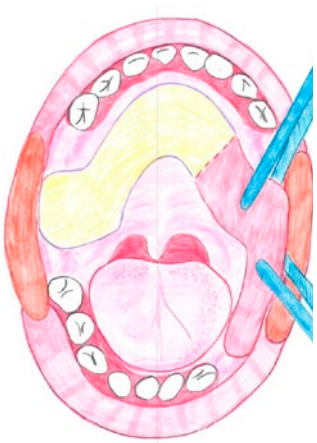

Fig. 3. Schematic representation of cutting out and transferring one of the supports of the tested flap

«Stavropol Regional Clinical Hospital» for the reconstruction of the alveolar ridge using a vascularized palatine mucoperiosteal flap. According to the methods of additional visual studies and clinical examination, the patients had subtotal mandibular defects, ranging from 2 to 5 teeth in the lateral segment of the mandible with a deficiency of connective tissue structures (*Figure 1*). Surgical interventions, fixation of personal and other data of patients were carried out after signing an informed voluntary consent to participate in a clinical trial. Patients with no consent to participate in it, somatic pathology in the acute stage were excluded from the study.

In 31 patients, surgical interventions were previously performed in other institutions with the use of free palatine autografts, which did not bring the proper result. The tested method was carried out under anaesthesia, the restoration of the volume of soft tissue structures was performed in 3 stages with the movement and fixation of the flap both along the top of the alveolar ridge, and from the vestibular and lingual sides. Surgical protocol: under conditions of local anesthesia, at the first stage, detachment of the mucoperiosteal flap is performed along its entire length, while maintaining 3 supports of the tested flap (*Figure 2*).

To prevent refixation of the flap to the bone base of the hard palate, an insulating pad was placed on its surface for a period of up to 5–7 days. At this time, the flap supports were subjected to daily "training" by applying hemostatic clamps at least for 5 minutes. The readiness of supports for transfer was determined by the time of restoration of blood circulation in the flap after removal of the hemostatic forceps.

At the second stage, one of the supports of the tested flap was cut off with its transfer to the projection of the recipient bed (*Figure 3*).

The preparation of the recipient bed consisted in making an H-shaped incision along the top of the alveolar ridge in order to expose its top from all sides and to fix the flap stem in the required position, corresponding to the greatest degree of bone tissue atrophy, with the prevention of the formation of «pockets» and «infringements». At the same stage, intermaxillary fixation was installed to prevent the detachment of the flap stem. Fixation was carried out for a period of up to 10 days with daily "training" of the flap. At the third stage, the second leg of the flap was cut off and spread over the top of the alveolar ridge. The third preserved support was split and positioned in such a way as to cover the bony base of the hard palate (*Figure 4*). Intermaxillary fixation was previously removed at the third stage.

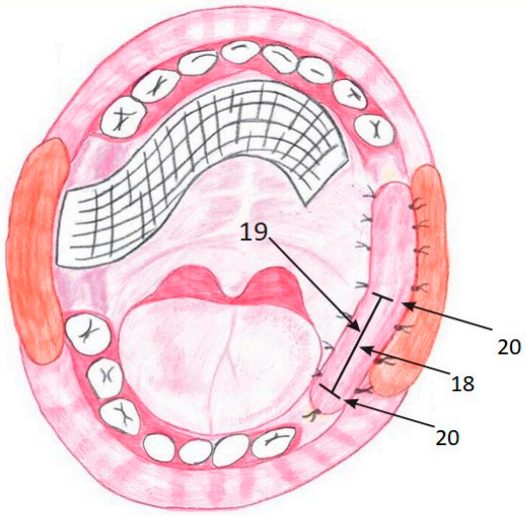

Fig. 4. Schematic representation of the recipient bed after fixation of the legs of the vascularized flap

Results and discussion

Dynamic observation was carried out in the early and late postoperative periods. In the early postoperative period, on the 12th day, the restoration of soft tissue structures in a volume of at least 2 cm^2 in patients who underwent the tested surgical intervention, at the top of the alveolar ridge, the height is at least 16 mm, and the thickness is at least 20 mm. One month after surgery, the height is not less than 15 mm; the thickness is not less than 20 mm. By the end of the third month, the indicators remained stable and corresponded to the previous figures, which indicates the absence of a shrinkage mechanism and the stability of soft tissue structures. In 31 patients who had previously undergone augmentation using free grafts, only remote dynamics could be monitored, after 21 days, at the end of the first and third months. In the absence of preoperative data, metric parameters were examined using a Michigan probe. On average, the height of soft tissue structures at the top of the alveolar ridge did not exceed 5 mm; the gum biotype was thin. In 27 patients, cicatricle changes in the mucous membrane covering the alveolar ridge were noted, creating additional tension in the soft tissue structures, which did not allow to proceed to the stage of bone augmentation and (or) dental implantation. In 4 patients the height of soft tissue structures in the projection of the top of the alveolar ridge on the 21st day was 6 mm, the mucosa is pliable, slight cicatricial changes are visualized, while by the end of the third month the height changed in the negative direction, descending to 3–4 mm, which is most likely, was equal to the units of the preoperative period. On average, the height of soft tissue structures at the top of the alveolar ridge did not exceed 5 mm; the gum biotype was thin. In 27 patients, cicatricial changes in the mucous membrane covering the alveolar ridge were noted, creating additional tension in the soft tissue structures, which did not allow to proceed to the stage of bone augmentation and (or) dental implantation. In 4 patients, the height of soft tissue structures in the projection of the top of the alveolar ridge on the 21st day was 6 mm, the mucosa is pliable, slight cicatricial changes are visualized, while by the end of the third month the height changed in the negative direction, descending to 3–4 mm, which is most likely, was equal to the units of the preoperative period. On average, the height of soft tissue structures at the top of the alveolar ridge did not exceed 5 mm, the gum biotype was thin. In 27 patients, cicatricial changes in the mucous membrane covering the alveolar ridge were noted, creating additional tension in the soft tissue structures, which did not allow to proceed to the stage of bone augmentation and (or) dental implantation. In 4 patients the height of soft tissue structures in the projection of the top of the alveolar ridge on the 21st day was 6 mm, the mucosa is pliable, slight cicatricial changes are visualized, while by the end of the third month the height changed in the negative direction, descending to 3–4 mm, which is most likely, was equal to the units of the preoperative period, covering the alveolar ridge, creating additional tension on soft tissue structures. In 4 patients the height of soft tissue structures in the projection of the top of the alveolar ridge on the 21st day was 6 mm, the mucosa is pliable, slight cicatricial changes are visualized, while by the end of the third month the height changed in the negative direction, descending to 3–4 mm, which was equal to the units of the preoperative period, covering the alveolar ridge, creating additional tension on soft tissue structures, which did not allow to proceed to the stage of bone augmentation and (or) dental implantation. In 4 patients the height of soft tissue structures in the projection of the top of the alveolar ridge on the 21st day was 6 mm, the mucosa is pliable, slight cicatricial changes are visualized, while by the end of the third month the height changed in the negative direction, descending to 3–4 mm, which is most likely, was equal to the units of the preoperative period.

Conclusions

Soft tissue augmentation for extended defects of the jaw bones requires a radical approach with the use of wide volumetric flaps that can't give a high success rate in the late postoperative period. The applied standard free flaps have a number of advantages: minimally invasive intervention, an accelerated rehabilitation period, while a high shrinkage coefficient, lack of proper integration and the formation of cicatricial deformities do not allow timely and in the absence of risks to proceed to the subsequent stages of rehabilitation of the dentoalveolar system. The tested method, despite the aggressiveness of the surgical stages, makes it possible to achieve a hypervolume of the mucous membrane, which, according to morphometric parameters, is closest to the tissues covering the alveolar ridge.

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THE USAGE OF THE FINITE ELEMENT ANALYSIS IN THE DESIGN OF NEW DENTAL IMPLANT SYSTEMS

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SUMMARY

Introduction. *The development of new dental implants in the context of the booming domestic industry makes it possible to find alternative options in the treatment of clinically difficult situations, to select the necessary individual solution during dental implant surgery and consequently to perform the surgery in an error-free manner and achieve the desired results. The development of a dental implant is a multistep process, and the characteristics of the implant material and its biophysical characteristics must be studied in detail until the implant is integrated into the bone tissue.*

The aim of the study: *to estimate the opportunities and prospects of applying the finite elements method by developing the new systems of dental implants according to the literature data.*

Materials and methods. *A search was carried out in the national digital libraries e-library, CyberLeninka, as well as PubMed, Medline, Web of Science and Google Scholar using the following keywords: dental implant, finite-element analysis, mathematical model. Sixty-nine papers were selected and analysed.*

Results. *The finite element method is an accurate method to analyse the implant being developed, but it has certain limitations, because in the finite element mesh, the implant-bone interface is a continuous relationship. The absence of micro-movement at the implant-bone interface during loading is different from the actual clinical situation. The expected 100% osseointegration based on 3D-modelling can't be an ideal option and never corresponds to the reality in the clinical situation. However, the use of the finite element method makes it possible to test single loads and inclination angles, which in the clinical situation is very rare.*

KEYWORDS: *biocompatibility, osseointegration, biomechanics, dental implant, finite element analysis, mathematical model.*

CONFLICT OF INTEREST. *The authors declare no conflict of interest.*

Introduction

Today, issues related to achieving positive results in dental implant surgery have received considerable attention. This is due to the expansion of a number of techniques, surgical techniques, a wide range of dental surgeons, especially in view of the widespread development and implementation of digital dentistry, and new types of implants [1, 2].

At the time of dental implant development, the study of biophysical characteristics is traditionally considered of paramount importance. This is due to a number of factors, which undoubtedly include the response of bone tissue to the foreign body, the loading ratio of the dental implant and bone, as well as the distribution of forces at the implant-abutment junction. In the case of dental implants, the following features should be noted:

- nature of the failure: fatigue or temporary (static);
- the condition of the bone, both at the implant site itself and in the surrounding bone tissue;
- the condition of the implant fixation nodes;
- the degree of osseointegration of the implant at different sites.

In the body of knowledge required by the dental implantologist using dental implants, the fundamentals of biomechanical reasoning for the decisions he or she makes are of particular importance [3].

Inadequate biomechanical analysis in the design, fabrication and application of dental implants can lead to a lack of formation of the bone-implant interface as well as short duration of their function, which in turn affects the patient and leads to negative feedback.

The aim of the work was to examine the publications available in digital libraries, which included information on the possibilities and peculiarities of applying the finite element method to the development of new dental implant systems**.**

Materials and methods of research

Scientific sources indexed in PubMed, Medline, Web of Science and Google Scholar were analysed in this study. The sources describing the original research in this area focused on the prototypes of the implants being developed, stress distribution on the adjacent bone, the biomechanics of the dental implant and bone, and the implant-bone interface.

Results and conclusions

Dental implants made of titanium (Ti) and its alloys (roxolide, titanium-zirconium alloy) are one of the most reliable alternatives for replacing missing teeth due to their optimal

а б

Fig. 1. Dental implants (a) and 3D model of the mandible with dental implants with abutments (b)

biomechanical properties [66, 68]. Almost all existing implants are made of titanium, which has a hard structure and a higher strength that is 5–10 times stronger than bone [4]. It is worth noting that a significant mismatch between implant strength and bone strength can contribute to overloading, aseptic inflammation and bone resorption [5–10].

Currently, the development of new dental implant systems is based on the principles of optimising implant physical density and bone simulation [11–16] to overcome the aforementioned complications and achieve complete bone remodelling.

Thus, this process can be influenced by many factors such as implant material and design [17–21], implant surface [22–25] and bone quality [9, 26–29].

Implants have a higher physical density and are able to absorb more load and transfer less stress to the surrounding bone tissue. The amount of deformation in the surrounding bone determines the remodelling process under occlusal loading [30, 31], as proven by Wolf's transformation law.

Harold Frost [32] described the mechanostatic theory as changes in strain levels and corresponding changes in bone density. Bone density is a value that is often used to assess clinical evidence of bone health. Each individual may have a different bone density. In addition, bone density varies in different age and gender groups [33].

To overcome the aforementioned complications, many researchers are working on the development of new materials and bioinspired structures using both standard solutions and additive technologies (3D-printing) to recreate mechanical properties that are well compatible with bone tissue [23, 34, 35, 36]. To simulate different bone densities, implant designs and various mechanical loads, computer methods are actively used in the evaluation of implant biomechanics [37, 38]. The most relevant method for modelling and calculating the strength and reliability of developed products is the usage of modern computer-aided engineering analysis packages, with ANSYS [39] being the most effective computer-aided engineering (CAE) system for modelling the functional processes of such products.

The main method of computer simulation is the finite element analysis (FEA), which allows the calculation of the stress-strain state (SSS) arising within a mechanical system under the influence of external forces, as well as displaying the areas of the structure where material deformation and subsequent failure occurs [40]. The calculated finite element method of stress analysis may not exceed the stress limit values.

It is important to consider that the transfer of stress between the implant and the bone depends on a number of factors and the description of this process is quite extensive. In order to realise the biomechanical effects, a 3D mathematical model is used, in which the geometric data of the implant, the mechanical properties of the bone and the parameters of the bone-implant interface are defined, otherwise known as a finite element network [41–44]. By modifying the individual elements of this system, it is possible to obtain data on the clinical performance of the dental implant.

Thus, by studying the biomechanical features of dental implants, biomechanical changes and VAT can be fully determined, which in turn will help to further improve implantation techniques and increase the effectiveness of the treatment performed [45].

At the time of creation of a dental implant, methods for biomechanical evaluation of its effect on the bone-implant interface are actively used to predict the behaviourof the implant directly in the bone tissue and to assess its advantages and disadvantages [46]. To study the biomechanical effects, a computer model (*Figure 1*) with predetermined dental implant specifications is used to digitally construct a finite element model of the jaw region with the dental implant (bone tissue parameters are determined in advance based on already available data).

Korioth, T.W. and Hannam, A.G. [44] reflected one of the first works on the application of the finite element method to biomechanical analysis in dentistry. More recently, Van Staden, R.C. et al. [47] in their work indicated that finite element method (FEM) should be considered a numerical method for the analysis of strains and stresses in any given structure. Today, FEM is a widely used method in the field of dental biomechanics [48].

A study based on the FEM using simplified models, allows «pure experimentation», i.e. to exclude all irrelevant factors inherent to the real object, with the properties of FEM models being as close as possible to the real object [49].

During the development phase of a dental implant, a finite element model is used to assess the technical characteristics and will overwhelmingly consist of several parts (*Figure 2*), namely the jaw cortical bone, jaw trabecular bone, dental implant, abutment and abutment screw, and the crown and its fixation method [9,46,50].

The properties of the dental implant materials to be used in the biomechanics simulation must be specified in advance. The materials must be homogeneous, isotropic and linearly elastic.

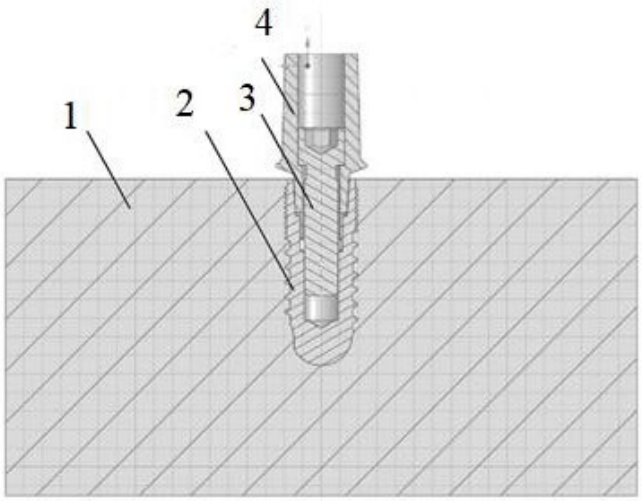

Fig. 2. Finite element model for dental implant design: 1 – bone block, 2 – implant body, 3 – screw, 4 – abutment

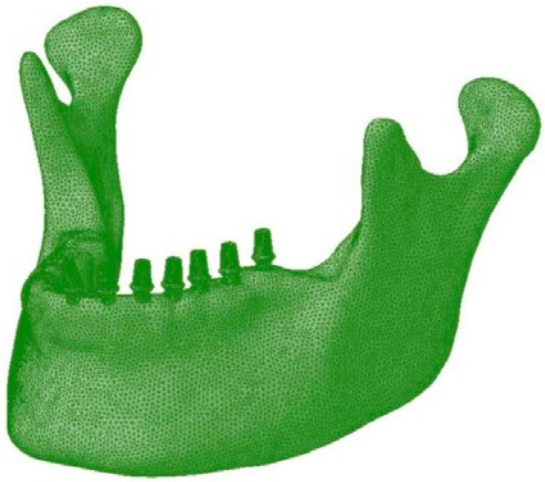

Fig. 3. Grid element in the computer model

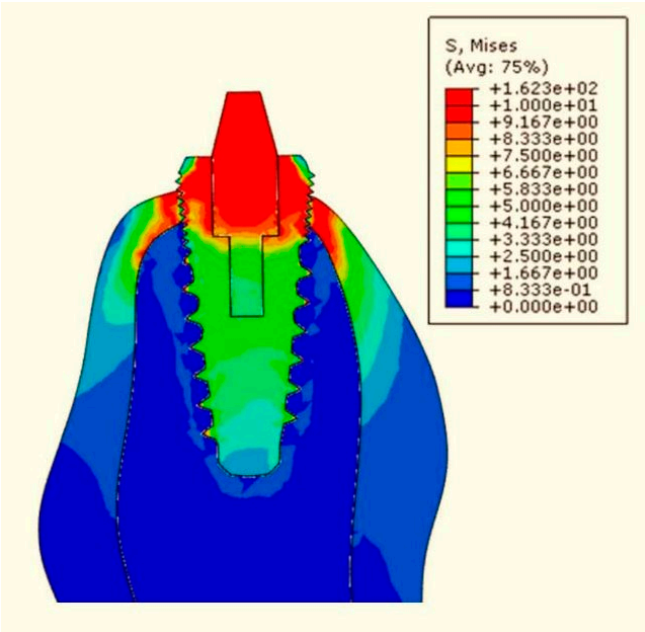

Fig. 4. Von Mises load distribution

Therefore, 2 independent parameters (Young's modulus (E) and Poisson's ratio (ν)) are often used to indicate material properties.

The mesh element used in the finite element computer model is a tetrahedral mesh [51,52] (*Figure 3*).

In most cases, it is necessary to use a finite element mesh model to determine the various occlusal conditions on the dental implant system to be designed.

FEM makes it possible to assess the distribution of reaction forces and structural stresses at the fixed upper end of the abutment in a dental implant system [20,53].

With the mathematical model, it is possible to estimate the von Mises stress distribution in the modelled bone area (*Figure 4*). Moreover, when examining the load on the alveolar bone in the areas of a single tooth, it can be seen that the areas in connection with the cortical bone have a higher stress. The occurrence of this high stress can be explained by Hooke's law (stress = Young's modulus × strain). When a dental implant system receives an external force, it will have a slight downward displacement, compressing the alveolar bone and creating the same displacement at the junction of the cortical bone and the trabecular bone (creating the same deformation here) [12]. The stress is proportional to the Young's modulus. The cortical bone above the alveolar bone therefore has a higher stress (54). Therefore, the design of some implants increases the number of microthread coils on the implant neck, increasing its contact area with the alveolar bone surface, preventing the dental implant system from loosening when exposed to external forces, thereby increasing implant success.

The von Mises load distribution of the bone-implant system shows that high loads on dental implants due to external forces mainly occur near the dental implant neck, where the dental implant contacts the abutment. Therefore, when a tooth receives an external force, it directly deforms the neck of the dental implant. According to Hooke's law, high stress will be generated in this area. [10].

It is worth noting that the alveolar bone adjacent to the implants that have been exposed to external forces will also be highly stressed due to deformation (44).

When assessing the stress on the abutment and abutment screw, it can be seen that high stress on the abutment occurs at its junction with the dental implant [55, 56]. High stress on the abutment screw occurs in the area where the screw head is connected to the abutment, also corresponding to the area where the geometric shape of the screw head and screw are bent. Therefore, the design of abutments and abutment screws should avoid the generation of high stresses by the geometric shape. Otherwise, since the patient will be using the structure for an extended period, the dental implant system may be damaged due to material fatigue (57, 58).

In obtaining unique dental implant models, and specifically in the design phase of their development today, a self-adaptive 3D model is used, which in contrast to traditional approaches in parameterised self-modifying implant models, assembling self-adaptive 3D models, transferring bi-directional parameters and adjusting variables [59].

Building a parametrized self-modifying implant model means that the implant model is built based on the diameter and length of the implant. In other words, the amount of implant

threading can be changed with automatic changes in implant diameter and length. Assembling self-adaptive 3D models means that all models are rebuilt based on implant parameters. That is, the parameters of other parts (bone types) were changed while automatically changing the implant parameters [4, 58].

CAD (Pro/E) and CAE (ANSYS Workbench) bidirectional parameter transfer tools can transfer model parameters mutually and seamlessly. The variable settings include input variables (D and L) and output variables (max EQV stress in the mandible and max displacement in the implant-abutment complex) [38, 39].

Results

FEM is an accurate method to analyse the implant under development, but has certain limitations because in a finite element mesh, the implant-bone interface is a continuous relationship. The absence of micro-movement at the implant-bone interface during loading is actually different from the actual clinical situation [28, 60].

The expected 100 % osseointegration based on 3D modelling cannot be ideal and never corresponds to reality in the clinical situation. The bone (cortical, cancellous) and the implant are thought to be isotropic and homogeneous, but in real, the bone is anisotropic and heterogeneous. The implant is rigidly fixed in the bone. Loads were only applied at point locations. The duration of force application in implants and the oral cavity is different [8, 61, 62].

In addition, the use of FEM, allows the testing of single loads and tilt angles, which is very rare in the clinical situation [25, 45, 57, 63, 64, 65].

In many scientific studies using the finite element method, most authors use optimum values and loads [66], but for a complete understanding of the biomechanical behaviourof dental implants, attention must be paid to all existing biomechanical modelling features.

Conclusions

The finite element method is an important tool in dental implantology, because it makes it possible to test prototypes of implants under development and to study the behaviour of existing modified implants in order to study stress distribution in adjacent bone, the biomechanics of the dental implant and bone, and the implant-bone interface.

A mathematical model including finite element analysis allows for predicting possible risks associated with overloading of the implant or possible complications at the time of loading.

The combined use of fatigue, aging, thermal and continuous mechanical cyclic loading in the analysis of dental implant prototypes makes it possible to generate the most effective medical devices from a clinical point of view.

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