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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.

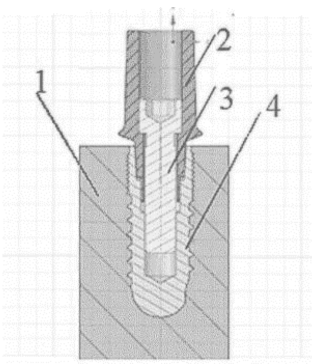

Fig. 1. Design of the Lico-M 4x10 dental implant: 1 – bone block, 2 – abutment, 3 – screw, 4 – implant body

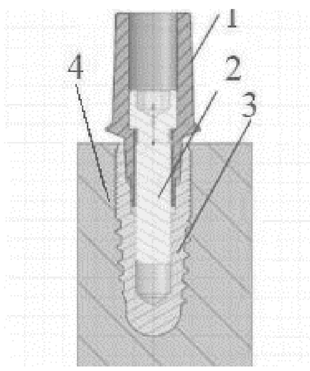

Fig. 2. Design of the Lico-M DG 4x10 dental implant: 1 – abutment, 2 – screw, 3 – implant body, 4 – bone block

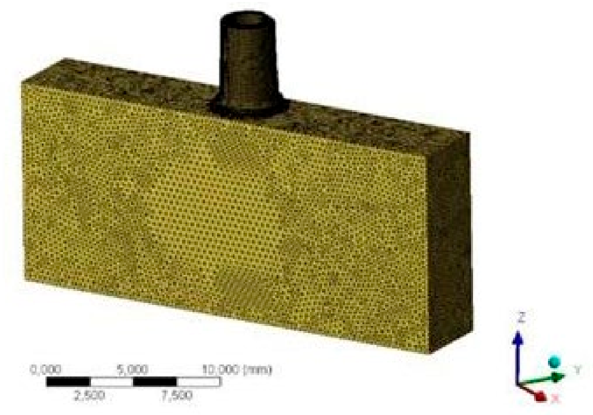

Fig. 3. Finite element grid of the Lico-M 4x10 implant

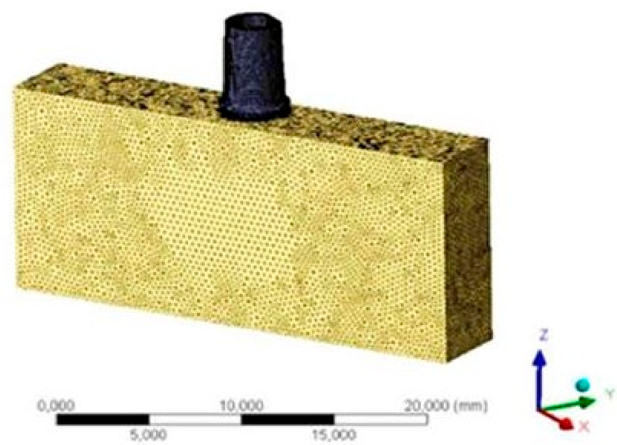

Fig. 4. Finite element grid of the Lico-M DG 4x10 implant

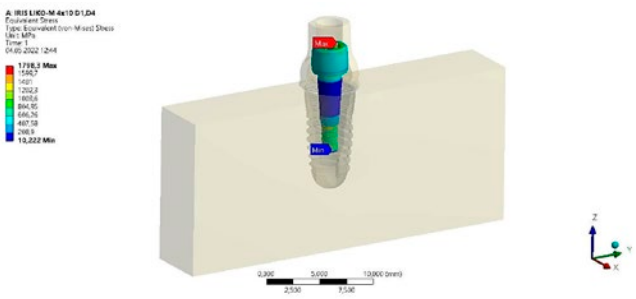

Fig. 5. Mises stress distribution of the Lico-M 4x10 dental implant screw *(time = 1 c)*

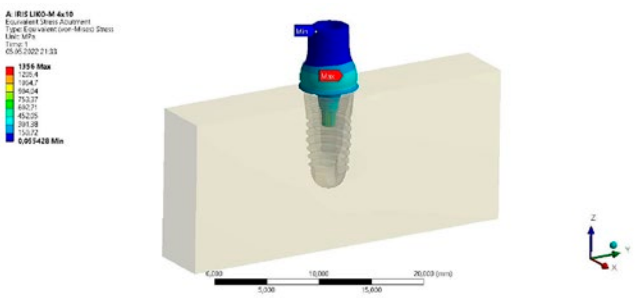

Fig.6. Distribution of Mises stresses in the abutment of a 4x10 Lico-M dental implant *(time* = 1 c)

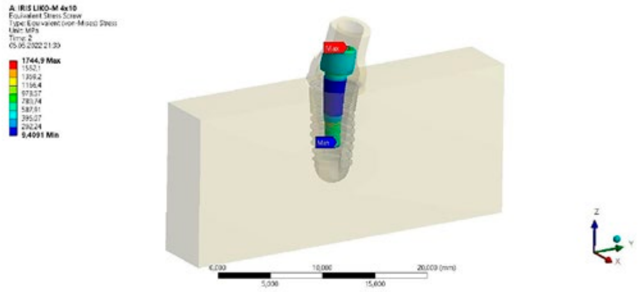

Fig.7. Mises stress distribution of the Lico-M 4x10 dental implant screw *(time = 2 c)*

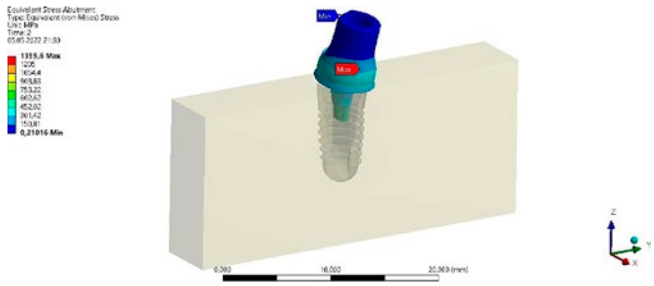

Fig.8. Distribution of Mises stresses in the abutment of a 4x10 Lico-M dental implant *(time* = 2 c)

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*.

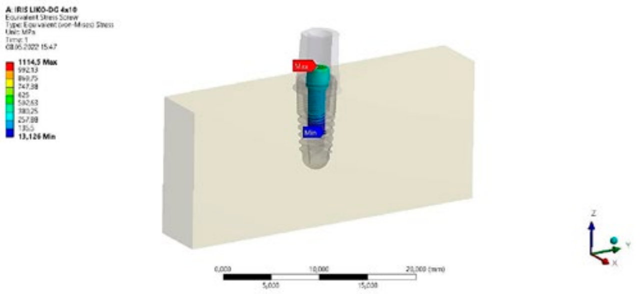

Fig.9. Distribution of Mises stresses in the screw of the Lico-M DG 4x10 dental implant *(time = 1 c)*

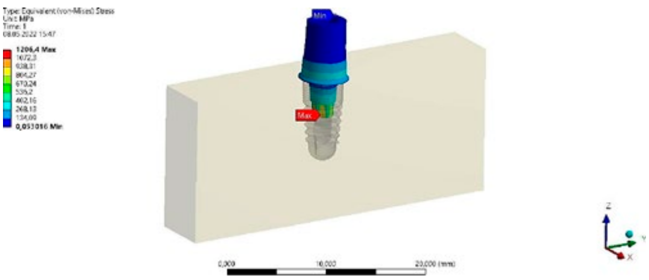

Fig.10. Distribution of Mises stresses in the abutment of the Lico-M DG 4x10 dental implant *(time = 1 c)*

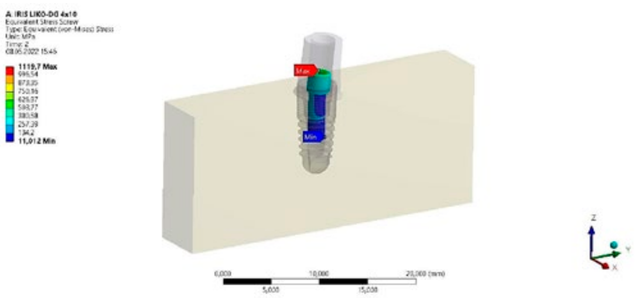

Fig.11. Mises stress distribution of the Lico-M DG 4x10 dental implant screw *(time =2 c)*

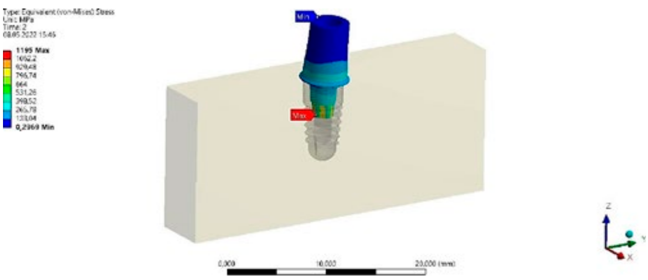

Fig.12. Distribution of Mises stresses in the abutment of a Lico-M DG 4x10 dental implant (time =2 c)

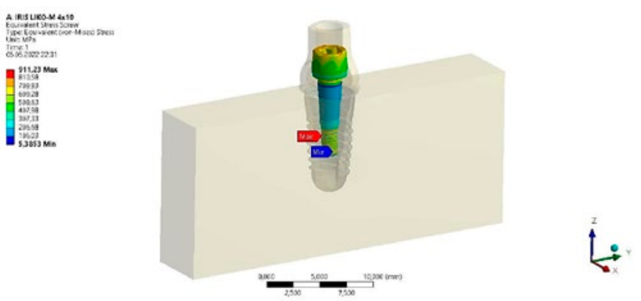

Fig.13. Mises stress distribution of the Lico-M 4x10 dental implant screw *(time = 1 c)*

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)*.

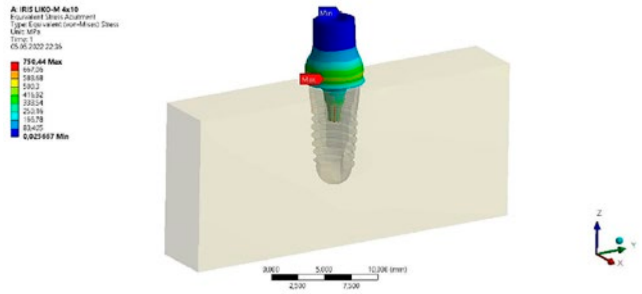

Fig.14. Distribution of Mises stresses in the abutment of a 4x10 Lico-M dental implant (time = 1 c)

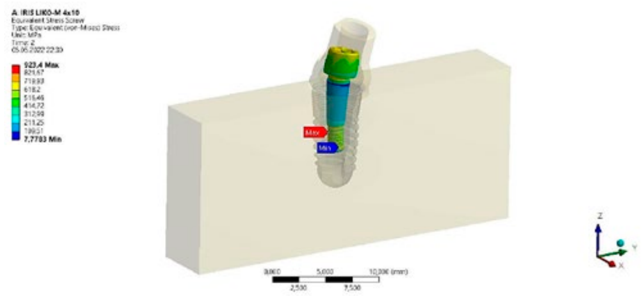

Fig.15. Mises stress distribution of the Lico-M 4x10 dental implant screw *(time = 2 c)*

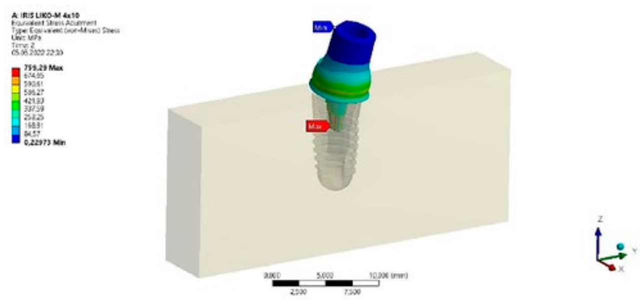

Fig. 16. Distribution of Mises stresses in the abutment of a 4x10 Lico-M dental implant (time = 2 c)

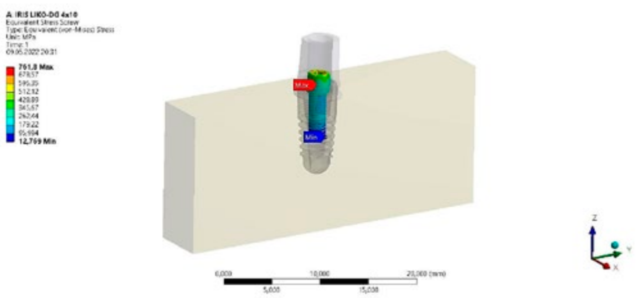

Fig. 17. Mises adjusted stress distribution of the Lico-M DG 4x10 dental implant screw (time = 1 c)

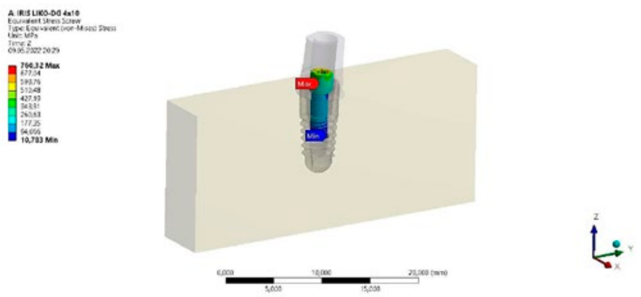

Fig.19. Mises stress distribution of the Lico-M DG 4x10 dental implant screw *(time =2 c)*

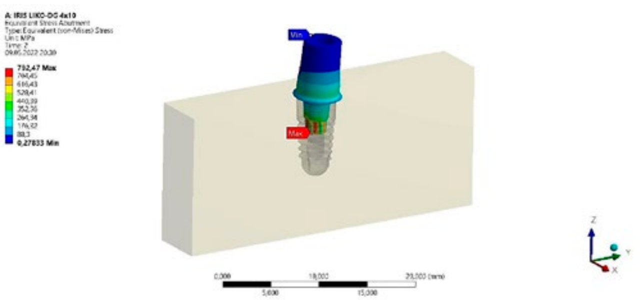

Fig.20. Distribution of Mises stresses in the abutment of a Lico-M DG 4x10 dental implant (time =2 c)

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

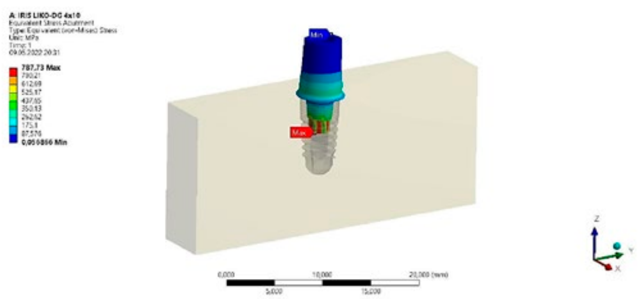

Fig.18. Distribution of Mises stresses in the abutment of a Lico-M DG 4x10 dental implant (time = 1 c)

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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