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FINITE ELEMENT STRESS STATE ANALYSIS OF MINI DENTAL IMPLANTS

ANALIZA NAPONSKOG STANJA MINI DENTALNIH IMPLANATA KONAČNIM ELEMENTIMA

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Keywords
- mini dental implant
- finite element method
- biomaterials

Abstract

The paper deals with the application of finite element method in determining the stress state in dental implants with different geometries subjected to various loads. Models that included mini dental implants and the bone used as a support are made in SolidWorks® and exported to Abaqus®. Obtained results show which load case is the most favourable in terms of structural integrity of the implants, which is of great importance considering the widespread use of mini dental implants in biomedical applications.

Ključne reči
- mini zubni implantat
- metoda konačnih elemenata
- biomaterijali

Izvod

U radu je prikazana primena metode konačnih elemenata u određivanju naponskog stanja u zubnim implantatima različitih geometrija, koji su izloženi različitim vrstama opterećenja. Modeli se sastoje od mini implantata i kosti, koja je služi kao oslonac, i napravljeni su u SolidWorks® i potom izvezeni u Abaqus®. Dobijeni rezultati pokazuju najnepovoljniji slučaj opterećenja sa stanovišta integriteta mini implantata, što je od velikog značaja s obzirom na veliku primenu zbunih mini implantata.

INTRODUCTION

Dental implants have been widely accepted as a means of treatment of partially or completely toothless patients. An example of a conceptual solution for teeth replacement is shown in Fig. 1. It is well known that the interaction between the tissue and dental implant surface is of great importance for long-term prognosis. From the anatomical point of view, it is generally accepted that a dental implant must be in contact and integrated with several different types of host tissue. However, issues with achieving this were observed due to poor interaction between connective and epithelial tissues that resulted in the occurrence of permucosal closure, similar to what happens in the natural tooth structure.

Figure 1. Dental implants.

Dental implants represent specifically shaped objects made of adequate biomaterial, whose main purpose is to be built into the living tissue. A comparison of cross-sections of a healthy tooth and an implant is shown in Fig. 2. State-of-the-art implants are almost exclusively made using titanium or its alloys, since it exhibits superior overall behaviour compared to stainless steel and CoCr alloys, /1-6/. The basic prerequisite for implant biomaterials to be integrated with living tissues is the so-called biocompatibility. This means that such materials should not have adverse effects on the tissue, such as the irritation of the tissue and immune system. In addition, these materials should not change their physical and chemical properties when subjected to tissue fluids and metabolites within the organism.

Dental implants are stronger and more durable than their predecessors (denture and braces). They offer a permanent solution for tooth loss, and apart from this, can be used in combination with other procedures in order to achieve maximal efficiency. For example, a single implant can be used as support for the crown, thus replacing the missing tooth. It can also be used as denture support, by replacing multiple missing teeth.

MINI DENTAL IMPLANTS (MDI)

During the mid-eighties, Victor I. Sendax began work on developing mini dental implants for IMTEC company, /7, 8/. These implants initially had diametres between 1.8-3.3 mm, with a ball on top, so that they could retain the brace or a temporary denture. The initial success rate of this therapy was around 50 %, and implant design has changed in order to improve its effectiveness. Along with this change, the implantation process protocol was adjusted in order to achieve primary stability, which was necessary for indirect loads. Mini implants obtained their modern appearance in 1996, developed within the IMTEC corporation, /7/. They were certified as permanent implants by the American FDA agency (Food and Drug Administration).

Ever since Branemark, /9/, established the principles of osseointegration, dental implantology quickly developed into the most innovative field within dentistry. Osseointegration refers to the ability of the host issue to form a functional interaction with the implant and its surfaces, without an intermediary connecting tissue layer, which resembles a capsule of foreign tissue, visible when using an optical microscope.

There are currently over 200 implant manufacturers on the market along with over 1000 implanting systems. Numerous classifications of implants exist, depending on their purpose, means of implanting, shape, and dimensions. From the viewpoint of toothless jaws, where atrophied alveolar ridges are present, that limits the conditions for the installation of implants, the diametre of implants is of great importance. Unfortunately, there is not a strictly defined classification of implants based on their diametre, although certain classifications can be found in literature, including:

- standard diametre implants, greater than 3.3 mm;
- medium diametre implants, with diametres ranging from 2.8 to 3.3 mm, also known as reduced diametre implants;
- small diametre implants, hybrid implants, midi implants, and decreased diametre implants; and
- mini implants, with a diametre range of 1.8 to 3.3 mm.

Mini dental implants represent a very simple and cost-effective approach to stabilising of total dentures, while ensuring that wearing such implants becomes acceptable and unnoticed. Mini dental implants are shown in Fig. 3. The system typically consists of four mini dental implants built into the jaw and then fixed into the total denture using a special mechanism. After the total denture is made, implants are built into it, followed by the adaptation of the denture so that a system of stitches can be applied to it.

Another strategy involves placing of mini dental implants in locations which are too narrow. These are extremely useful for small teeth replacement and filling of smaller spaces between teeth.

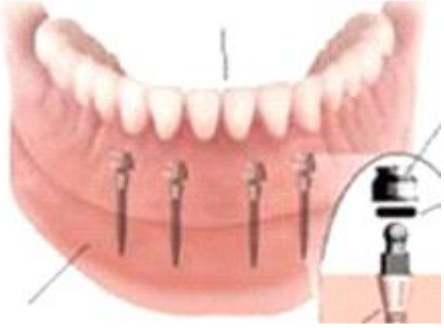


Figure 3. Mini implants /3/.

Modern mini dental implants (MDI) are one-piece Ti-6Al-4V component, with tensile strength 62.5 % higher than that of pure commercial type IV titanium. High value of tensile strength enables the installation of implants without the need for previous bone repairing.

NUMERICAL MODELS

Models of MDIs, as well as the bones, presented in this paper are made using SolidWorks® software, and exported to ABAQUS® afterwards.

SolidWorks® is used for machine design and process automation, which are based on parametric modelling of full bodies. It is also used as a platform software for numerous programmes.

Numerical analysis of stress states and displacements was performed using finite element method in ABAQUS® software. This software is used for modelling, analysis of mechanical components or assemblies and visualisation of results obtained by FEM. In addition, this software package can analyse FEM models designed in other types of CAD/CAE programmes.

DEVELOPMENT OF MDI MODELS

Three models of mini dental implants are made, for sizes of 10, 13, and 15 mm (a total of 9 models). Each of these implants was subjected to 3 load cases, including a horizontal, vertical, and inclined force of 800 N. Concentrated force was used for all three load cases.

Every finite element in the model must have certain elastic constants assigned to it. All materials are observed as linear elastic and for this reason, the Young's modulus and Poisson's ratio are defined. Properties of the selected materials, along with appropriate coefficients used in this research are shown in Table 1.

Table 1. Selected material properties.

Implant material	Ti-6Al-4V
Young's modulus	105.2 GPa
Poisson's ratio	0.342
Yield stress	832.3 MPa
Bone	(cortical)
Young modulus	14 GPa
Poisson's ratio	0.30
Yield stress	113 MPa

Models of mini dental implants are made in SolidWorks® and are shown in Figs. 4 and 5.

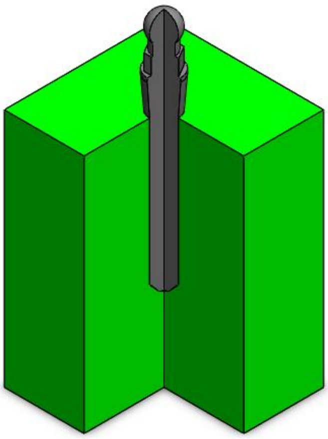
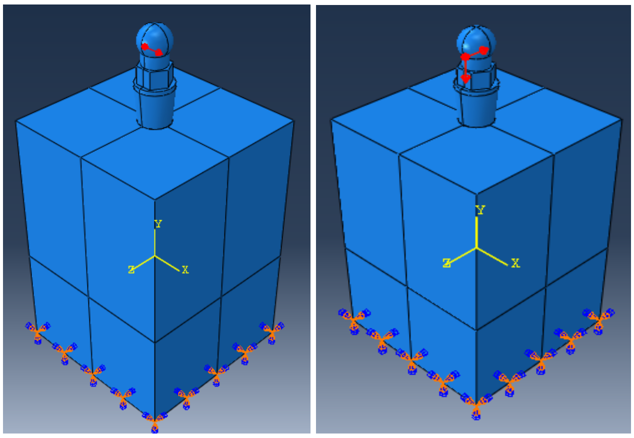


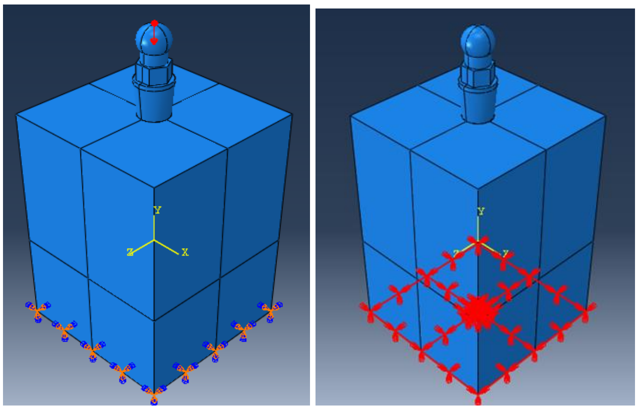
Figure 4. Mini dental implant geometry (10 mm size)

After MDI models are exported from SolidWorks® to ABAQUS®, simulations of load cases are performed, and their transfer from implant to bone is analysed. In the case

1.1, a 10 mm implant is subjected to a horizontal force of 800 N. Figure 5 shows locations of forces for all three cases, as well as boundary conditions.



a) horizontal force b) inclined force



c) vertical force d) fixed points

Figure 5. Load cases and boundary conditions.

DISCUSSION

The FEM application is justified by the complexity of bone, tooth, and implant geometries, since it possesses the unique ability to determine the stress state in biomaterials used in complex structures, often under complex loads. Table 2 shows the types and number of finite elements used for the bone and implant, along with the total number of nodes, for the 10 mm model subjected to a horizontal force of 800 N. The Von Mises stress distribution for this model is shown in Fig. 6, and for the 15 mm model in Fig. 7.

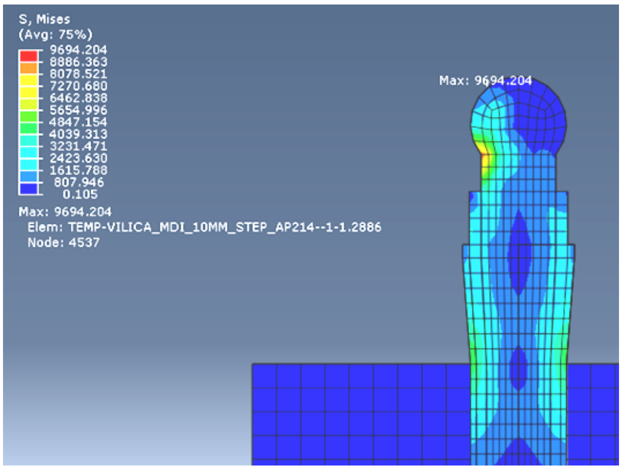
Table 2. Finite elements used in the models.

Bone:	
Element type	Hexahedral (C3D8R)
Number of elements	16 516
Number of nodes	18 758
Implant:	
Element type	hexahedral (C3D8R)
Number of elements	5 452
Element type	tetrahedral (C3D4)
Number of nodes	526
Total number of elements	5 978
Number of nodes	6 467

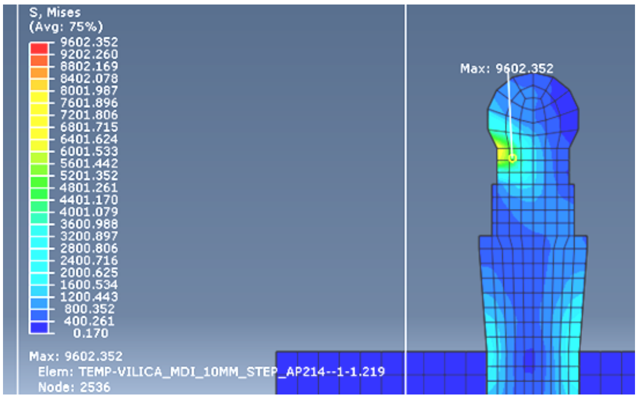
Table 3 shows maximal Von Mises stresses under a force of 800 N. FEM calculation here is done with force 800 N, which is unrealistic (used for finding out if plasticity would occur). Therefore, the last column presents values for 100 N force for easier comparison with the results in /10/.

Table 3. Maximal Von Mises stresses.

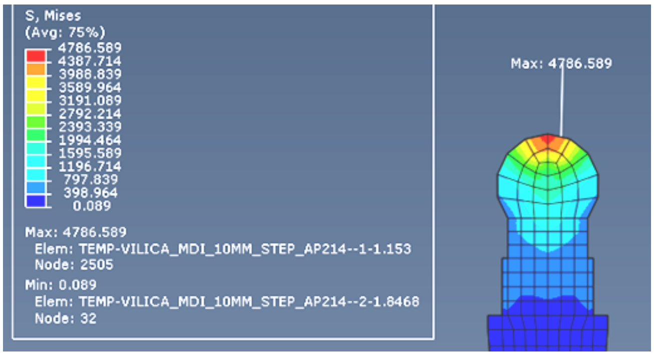
Force direction	MDI length (mm)	von Mises max. 800 N (MPa)	von Mises max. 100 N (MPa)
Horizontal	10	9694	1212
Inclined		9602	1200
Vertical		4786	598
Horizontal	15	4846	606
Inclined		5193	659
Vertical		2892	362



horizontal force

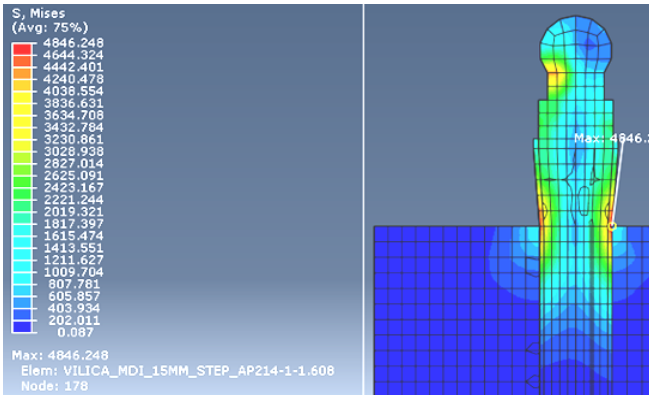


inclined force

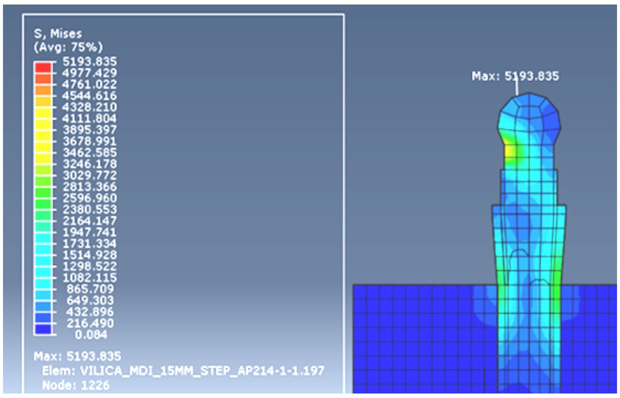


vertical force

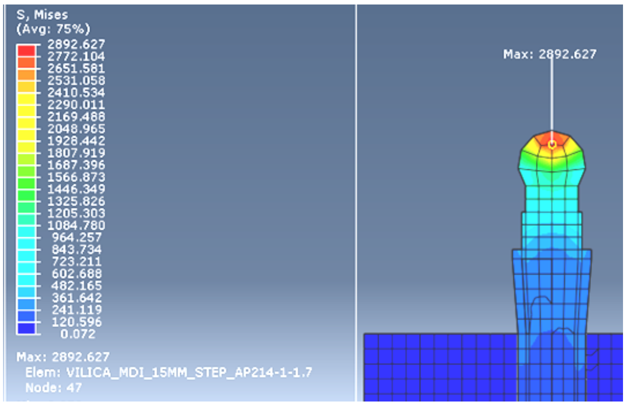
Figure 6. Von Misses distribution for 10 mm implant.



horizontal force



inclined force



vertical force

Figure 7. Von Mises stress distribution for 15 mm implant.

CONCLUSION

Intensity of loads that act on the crown and implant directly affect their work life. If this load is not transferred uniformly and is of high magnitude, the implant could be subjected to overloading in a single point, which can lead to fracture. In order to increase the life of implants as much as possible, it is necessary to decrease the stresses that occur in it. Research presented in this paper leads to a conclusion that adopting of an inclined load (force acting at an angle of 45°) results in a more favourable stress distribution, since the load is decomposed into a horizontal and a vertical component. Furthermore, the less favourable stress distribution occurs in the case of a horizontal force, wherein the stress is concentrated not only in the implant neck area, but also in the contact area between the bone and implant. In the case of a vertical force, stress is mainly concentrated in the implant head. It was also determined that maximal stress decreased for longer implants.

Based on the results shown in the above table, it can be concluded that the maximal stresses occurred in the case of horizontal load in the 10 mm model.

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