Original Article

STRUCTURAL AND MECHANICAL ASSESSMENT OF DENTAL IMPLANTS BASED ON TiO_2 AND ZrO_2

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ABSTRACT

At the stages of choosing a design and during the installation of a dental implant, its optimal parameters are taken into account. The determination of these parameters depends on the volume of bone tissue of the lower jaw and its mechanical properties. When choosing a design, it is necessary to assess the level of violations developing in the process of functioning. This article discusses two types of systems TiO_2 implants and structures made of ZrO_2. The possibility of using implants based on ZrO_2 is evaluated by analyzing the stress-strain state of both the implant itself and the implant–bone zone, where large stress differences occur. This property makes it possible to ensure better compression performance of the implant during biting. In this task, the implant mainly works on bending, and the less its bending is, the less impact it will have on the bone tissue in the cervical region. It can be concluded that an implant made of ZrO_2 causes less stress than an implant made of zirconium alloy under lateral loading during chewing.

Key words: Dental implant, Titanium, Zirconium, Oxides, Mechanical properties.

Introduction

When even one tooth is lost, functional stresses are redistributed in the maxillary system – teeth are displaced to the area of the formed defect, and the periodontal of the remaining teeth is overloaded [1]. The expediency of replacing defects in the dentition is beyond doubt. In recent years, the interest of specialists in the use of the dental implantation method in a wide dental practice has been increasing [2].

Dental implants have proven to be extremely reliable artificial intraosseous supports of dentures. Their demand in modern dentistry is because only dental implants create the possibility of replacing extended defects of dentition with fixed prostheses [3, 4]. The history of successful clinical use of implants is half a century and is largely explained by the biocompatibility, technological processing, and strength of the main structural material of implants [5]. At the same time, one of the main aspects at the stages of the patient's examination is to determine the conditions for the installation of an intraosseous implant, in particular, the availability of sufficient bone tissue and the choice of the optimal implant design [6-8].

Titanium implants are most widely represented on the Russian market, but recently zirconium dioxide structures have been used [9]. To justify the use of new implant designs, it is necessary to make sure that they are resistant to loads formed during the chewing function [10]. Both TiO_2 and ZrO_2 have high strength, hydrophobicity, biocompatibility, and low toxicity [11-13]. The chemical composition of the alloy determines its mechanical properties. Zirconium alloys belong to the group of alloys with solid-solution hardening and differ from intermetallic alloys, i.e. those prone to magnetization, including titanium, by high fatigue endurance characteristics that do not depend much on the structure of the metal [14]. The low structural sensitivity of zirconium makes it possible to expand the range of technological effects. It should be noted that zirconium materials tend to self-heal surface defects and are highly resistant to cracking [15]. Zirconium alloys are favorably distinguished from titanium alloys by the absence of hydrogen absorption and a tendency to hydrogen embrittlement at temperatures above 50-70 ºC in the air during processing [16]. The combination of high corrosion resistance in organic compounds, high processability, crack resistance, and fatigue endurance make zirconium alloys very promising for use in the production of endoprostheses [17].

The purpose of the work was to evaluate the ability of ZrO_2 implants to withstand the loads formed during operation and compare them with similar stresses that occur when using a TiO_2 implant.

Materials and Methods

In this paper, we consider the installation of an implant instead of a lost incisor. The use of TiO_2 and ZrO_2 implants is not only because they are durable, but also bioinert materials. The installation of implants in the incisor area is because the implant must withstand the loads that fall on it during chewing, as well as being aesthetic since the front teeth are exposed when smiling [18]. At the moment, dentists prefer to install implants made of ZrO_2, which has a white color in contrast to gray metals.

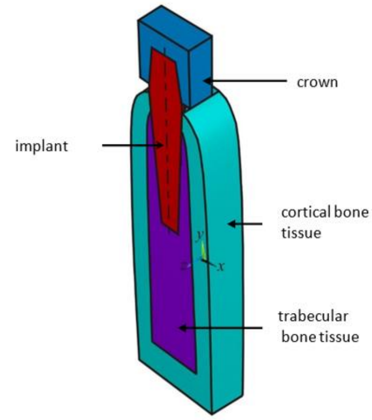
In this work, a model of the implant and the surrounding bone tissue is constructed for a three-dimensional situation. Consider the case when there is no central incisor on the lower jaw. **Figure 1a** shows a model of an implant with a smooth surface installed in the bone tissue of the lower jaw, in which the cortical (dense) and trabecular (spongy) layers are distinguished. The area of bone tissue and the implant is modeled as an area with different mechanical properties. The height of the lower jaw consists of two values: the average height of the lower jaw body (the distance from the lower edge of the jaw to the tops of the roots) is 18 mm and the height of the alveolar process is 11.5 mm [19]. The average length of the incisor is 21 mm (19-23 mm) [20], although in other sources it varies from 18.5 to 26.6 mm, while the crown height is 7.3–12.6 mm, the root height is 9.4–18.1 mm [21].

Table 1 shows the mechanical properties of TiO_2 and ZrO_2, as well as cortical and trabecular bone tissue. A full description of the properties and composition of an implant based on ZrO_2 is presented in the international standard ISO 13356, which regulates the limit values of stresses that an implant made of this material must withstand.

Figure 1b shows the boundary conditions:

a. static – a distributed load P = 45 H is applied normally to the surface of the crown mounted on the implant (half of the load equal to 90 H is applied, and the problem is solved for half of the implant and the load corresponding to the literature data on lateral loads that fall on the teeth during chewing [22]);
b. kinematic – all movements along all axes on the lower surface of the bone tissue are assumed to be zero [23].

To apply the load on the implant, we will place a crown in the form of a prism on its extra-costal part, the dimensions of which correspond to the dimensions of the incisor crown. The medial-distal size of the crown between the contact points range from 4.6 to 8.2 mm, and the neck – from 3.0 to 4.9 mm. The size of the crown in the vestibular-lingual direction in the equator area is from 5.2 to 7.4 mm, and in the neck area – from 4.3 to 6.8 mm.



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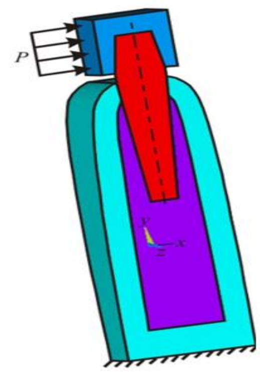

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Figure 1. Implant diagram: a) a model of an implant with a smooth surface with a crown installed on it and the surrounding bone tissue of the lower jaw, b) boundary conditions

Table 1. Mechanical characteristics of TiO_2, ZrO_2, ceramics, cortical and trabecular bone tissue

Material	Modulus of elasticity (E), MPa	Poisson's Ratio (ν)
TiO_2	$110 \cdot 10^3$	0,3
ZrO_2	$210 \cdot 10^3$	0,3
Ceramic	$170 \cdot 10^3$	0,3
Cortical bone tissue	$13{,}7 \cdot 10^3$	0,3
Trabecular bone tissue	$6{,}89 \cdot 10^3$	0,3

Results and Discussion

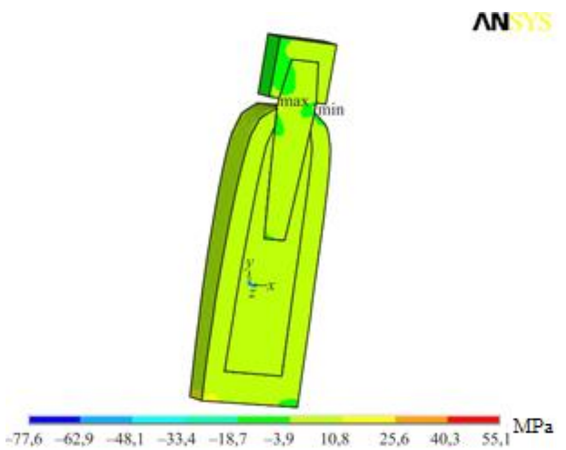
The problem of the stress-strain state of the implant in the bone tissue was solved within the framework of the theory of elasticity in the Ansys software package [24]. In the course of solving the problem, we will compare the stresses obtained with the strength limits of TiO_2, ZrO_2, and bone tissue, presented in **Table 2**. The strength limit of the trabecular bone tissue is assumed to be 10 times less than the corresponding strength limit of the cortical bone tissue.

Figure 2a shows the stress distributions along the X-axis and the Mises stress for implants made of ZrO_2. For comparison, we calculate the same problem for the case when the implant is made of TiO_2 **(Figure 2b)**. Analyzing the stress values obtained **(Figure 2)**, we conclude that the stresses do not exceed the strength limits for both the materials from which the implants are made and for bone tissue **(Table 2)**.

It should be mentioned that in the process of chewing, the implant is subjected not to a single load, but to cyclic loading since chewing food is because the lower jaw of a person performs vertical, horizontal, and transversal movements.

Table 2. Strength limits of TiO_2, ZrO_2, ceramics, cortical and trabecular bone tissue

Material	Tensile strength, MPa
TiO_2	200–400
ZrO_2	1400
Ceramic	250
Cortical bone tissue	130
Trabecular bone tissue	13



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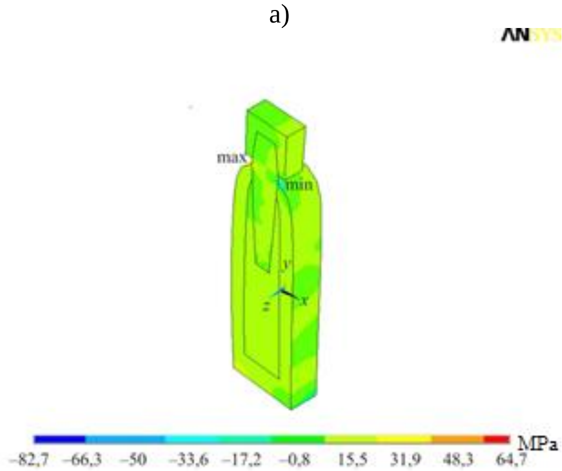

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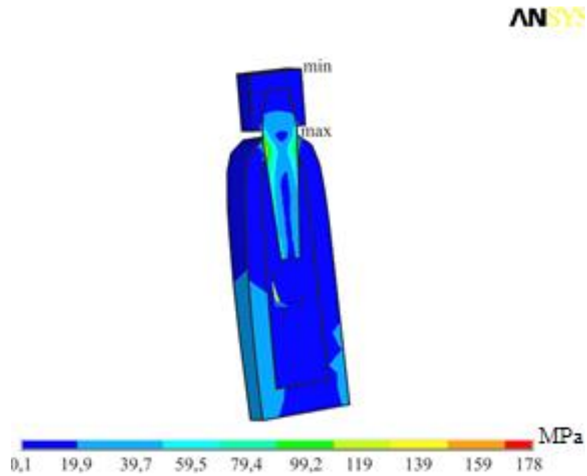

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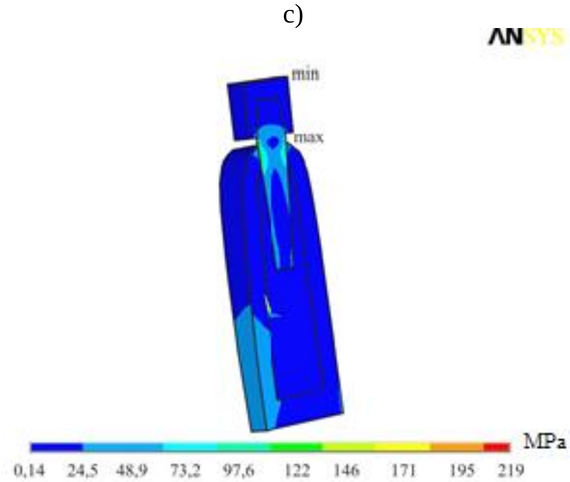

d)

Figure 2. Mechanical properties of implants based on TiO_2 and ZrO_2: stress distribution along the X-axis for an implant based on ZrO_2 (a) and TiO_2 (b) and the intensity of stress by Mises for an implant based on ZrO_2 (c) and TiO_2 (d)

The international standard ISO 13356 recommends the use of implants with fatigue stress limits exceeding 300 MPa. The fatigue stress limit for brittle materials is equal to:

$$\tau_{-1} \approx 0.8\, \sigma_{-1} \quad (1)$$

Where σ_{-1} – tensile strength.

Thus, in this work, ZrO_2 with a tensile strength of 1400 MPa was considered, therefore, the fatigue stress limit for this material is 1120 MPa. Comparing the obtained stresses with this limit, we obtain that ZrO_2 fully meets the strength requirements of the international standard for implants [25-27].

Conclusion

This article presents a comparative analysis of two types of dental implants made of titanium alloy and zirconium dioxide. The results of the study allow us to conclude that it is advisable to use implants made of zirconium dioxide in clinical practice. Compared with the implant, made of TiO_2 it showed the best results: stress in bone tissue in the area of bone – implant below ($\sigma_i = 178$ MPa, 13% σ_{-1}) than for the case of the implant from ZrO_2 ($\sigma_i = 219$ MPa, 73% σ_{-1}). ZrO_2 implant is more similar in mechanical properties to bone tissue, but the relative elongation of metal alloys is an order of magnitude greater than for bone tissue. This property makes it possible to ensure better compression performance of the implant during biting. In this task, the implant mainly works on bending, and the less its bending is, the less impact it will have on the bone tissue in the cervical region [28, 29]. It can be concluded that an implant made of ZrO_2 causes less stress than an implant made of zirconium alloy under lateral loading during chewing.

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Conflict of interest: None

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Ethics statement: None

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