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Comparative FEM study about various posts used on endodontically treated teeth

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ABSTRACT

Objectives. The aim of the present study was to analyze comparatively, through the finite element method (FEM), the biomechanical behavior of different types of devices used to increase the resistance of restorations on endodontically treated teeth, upon the experimental application of a force of 350N.

Materials and methods. We studied comparatively three types of posts, respectively: fiberglass post, cast post from Cr-Co-Mo alloy and prefabricated titanium post. Three irretrievable extracted teeth for periodontal reasons were endodontically treated and then specifically prepared for cementation of this devices. The teeth were scanned at a radio-diagnostic center, and the obtained DICOM files were processed with MIMICS and 3-matic and then subjected to finite element analysis with ANSYS.

Results. From the 48 simulations carried out for the case of all-ceramic crown coverage, the use of titanium post is associated with 25 situations in which maximum or minimum values appear, the use of cast post presents 12 situations in which maximum or minimum values are developed, the use of fiberglass posts is associated with 10 simulations where maximum or minimum values occur, and in one case the deformations are equal. Regarding the use of the zirconium oxide crown, the results are comparable.

Conclusions. The presence of zirconium oxide crowns generally produces less valuable stresses and deformations at the level of the components. The stress and strain values are lowest when using fiberglass posts, followed closely by cast post and far behind by titanium post. In all simulated situations, the limit values of stresses and strains are mostly recorded at the tooth root, which is susceptible to fracture in case of parafunctional forces, followed by the three devices themselves and the covering crowns.

Keywords: FEM, fiberglass post, titanium post, cast post, all ceramic crown, zirconia crown

INTRODUCTION

Finite Element Analysis (FEA) or Finite Element Method (FEM) is a computer-based numerical method in which a structure is analyzed on the principle of dividing the structure into a finite number of small elements, which are connected to each other by corner points called nodes [1]. For each element of the structure, depending on the displacement of the nodes, its mechanical behavior can be described. These nodes, if subjected to certain loading conditions, result in model behavior like the structure they represent [1]. When performing a finite element analysis, a system of simultaneous equations is solved that characterizes all the forces exerted on the nodes, as well as their displacement. From here, the stresses and deformations produced in each ele-

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ment can be determined, and by extrapolation the whole structure can be evaluated [2]. Due to the increased interest in the restoration possibilities of coronary lesions, many new dental biomaterials have been developed. But the elastic properties of these biomaterials should be close or like the properties of natural dental tissues, to reduce the stress concentration in the restorations and implicitly to decrease the incidence of therapeutic failure. An important cause of restorative failure is the lack of adequate understanding of the biomechanical principles involved in the dental restorative procedure. Therefore, to know the behavior of dental materials and tissue, biomechanical studies are crucial [3,4]. The aim of the present study was to analyze comparatively, through the finite element method, the biomechanical behavior of different types of devices used to increase the resistance of restorations on endodontically treated teeth, upon the experimental application of a force of 350N.

MATERIALS AND METHODS

The study was carried out with the consent of the Ethics Committee of the Faculty of Dental Medicine, Titu Maiorescu University from Bucharest (Decision no. 2 / 15.01.2018) and in compliance with the Declaration of Helsinki, without harming the patients or the environment, respecting human rights and having the written consent of the patients both for the inclusion in the study of the biological materials of human origin, respectively of the extracted irretrievable teeth, and for the use of study results for scientific purposes. We studied three extracted single-rooted teeth and three types of devices used to increase the strength of restorations on endodontically treated teeth, respectively: fiberglass post, cast post and prefabricated post from titanium. These three irretrievable extracted teeth were endodontically treated and then specifically prepared for cementation of the devices. After cementing the respective devices inside the root canals with PANAVIA SA produced by Kuraray Noritake Dental, the teeth were polished and imprinted with silicone through the sandwich technique to make cover crowns that were cemented on the abutments as well with PANAVIA SA. After each medical operation, the teeth were scanned at a radio-diagnostic center in Bucharest, and the obtained DICOM files were processed in the BIOMAT Research Center – Politehnica University of Bucharest with the software specialized in the three-dimensional reconstruction of the scanned parts (MIMICS, 3-matic) (Figure 1) and then subjected to finite element analysis with ANSYS (Figure 2). The STATIC STRUCTURAL finite element analyzes were carried out at a constant temperature of 35ºC, applying an experimental force of 350N perpendicular to the cover crowns, which was decomposed in the 3 directions as follows: on the OX axis: -45 N, on the OY axis: 45 N and on the OZ axis: -344 N. To simplify the calculations, in all three cases the possible displacements between the prosthetic crowns and the abutments, respectively between the devices used to increase the resistance of endodontically treated teeth and teeth itself, were blocked, considering the layers of fixation material of negligible thickness. Also, also to simplify the calculations, the composite materials used for the reconstruction of the abutments on the fiberglass post and the titanium post were not considered. To carry out the analyses, the following isotropic elasticity properties of the materials were considered:

- For dental tissues, Poisson's ratio = 0.24, Global Modulus = 6609 MPa, Transverse Modulus = 4157.3 MPa and Longitudinal Modulus = 10310 MPa.
- For zirconium oxide crowns, Poisson's ratio = 0.25, Global Modulus = 136670 MPa, Transverse Modulus = 82000 MPa and Longitudinal Modulus = 194000 MPa
- For all-ceramic crowns, Poisson's ratio = 0.22, Global Modulus = 11905 MPa, Transverse Modulus = 8196.7 MPa and Longitudinal Modulus = 20000 MPa
- For DCR, Poisson's ratio = 0.28, Global Modulus = 146970 MPa, Transverse Modulus 75781 = MPa and Longitudinal Modulus = 194000 MPa
- For titanium gear, Poisson's ratio = 0.31, Global Modulus = 105260 MPa, Transverse Modulus = 45802 MPa and Longitudinal Modulus = 120000 MPa
- For the fiberglass pivot, Poisson's ratio = 0.3, Global Modulus = 37500 MPa, Transverse Modulus = 17308 MPa and Longitudinal Modulus = 45000 MPa.

RESULTS

For each type of post and for each type of prosthetic crown were calculated total deformation, directional deformation (X, Y and Z), equivalent strain, maximum principal strain, minimum principal strain, maximum tangential strain, normal elastic strain (X, Y and Z), tangential strain (XY, YX and XZ), equivalent stress, maximum principal stress, minimum principal stress, normal stress (X, Y and Z) and tangential stress (XY, YZ and XZ). The centralized results of the calculated values are recorded in tables 1-6. From the 48 simulations carried out for the case of all-ceramic crown coverage, the use of titanium post is associated with 25 situations in which maximum or minimum values appear, the use of cast post presents 12 situations in which maximum or minimum values are developed, the use of fiberglass post is associated with 10 simulations where maximum or minimum values occur, and in one

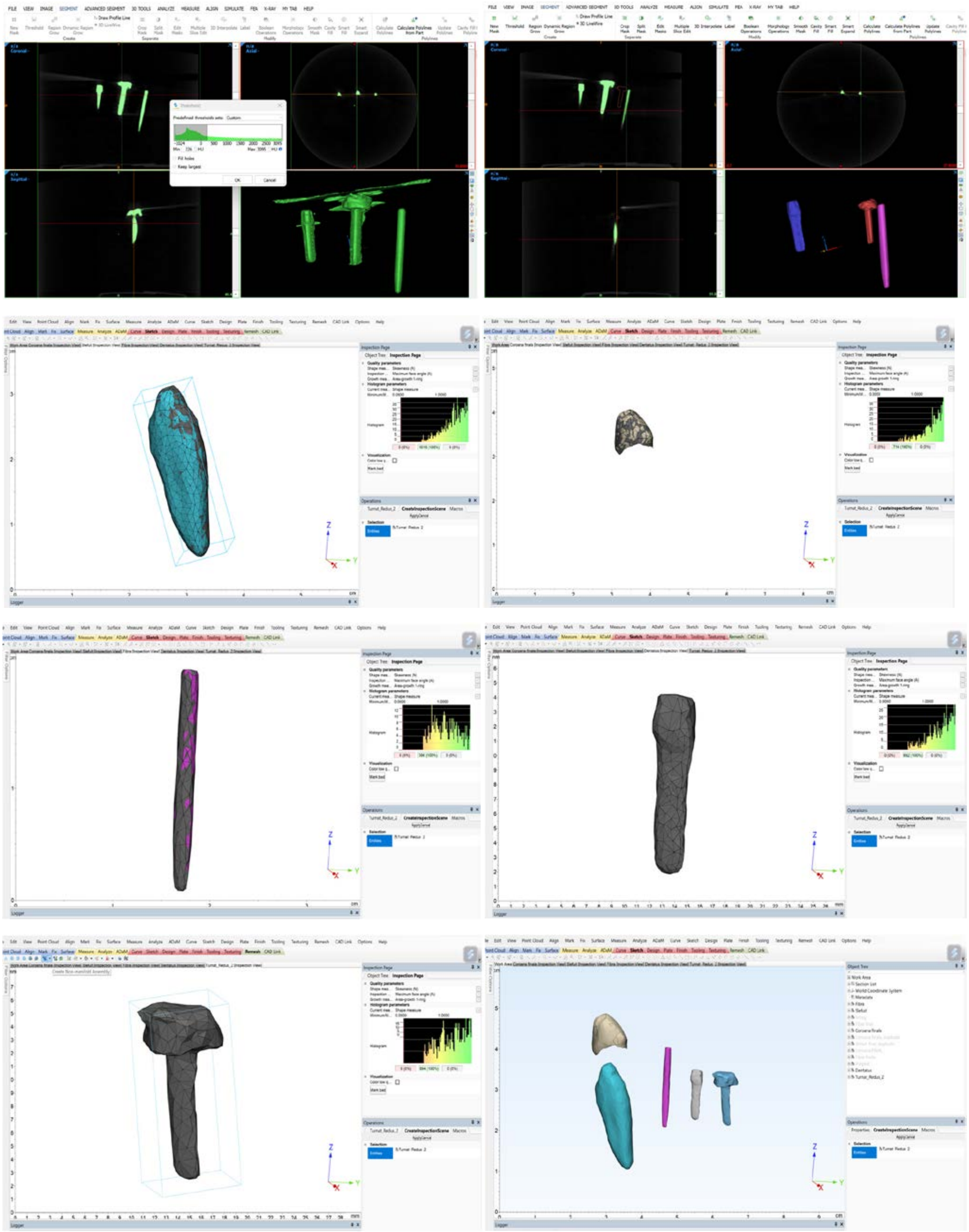

FIGURE 1. Examples of processing steps of DICOM image with MIMICS

case the deformations are equal. Regarding the most intensively requested component when covering with all-ceramic crowns, they are in descending order: the root (24 simulations), the post (16 simulations) and the prosthetic crown (7 simulations). In a single case, the maximum or minimum values appear on different areas depending on the type of device. Regarding the use of the zirconium oxide crown, the results are comparable. The use of titanium post is associated in 24 simulations with the de-

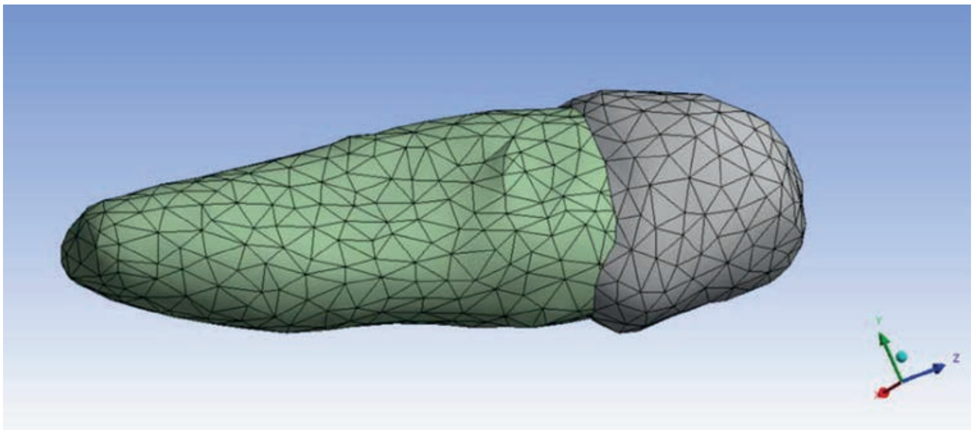

FIGURE 2. Decomposition into finite elements of the tooth-post-prosthetic crown assembly

velopment of maximum or minimum values, the application of cast post is associated with 16 simulations in which maximum or minimum values are developed, and the use of fiberglass post led to the development of borderline values in 7 simulations. A simulation assumed the development of equal strains. If we analyze the results obtained from the point of view of the more intensively stressed regions, the extreme values appear in 23 cases at the level of the tooth root, in 13 cases at the level of post, in 11 cases at the level of the prosthetic crown and in one case appear in different areas depending on the type of post.

DISCUSSIONS

Among the elements that characterize the devices for increasing the resistance of restorations on endodontically treated teeth, we find their dimensions (diameter, length), but also the modulus of elasticity of the materials from which they are made [5,6]. The choice of materials, but also of the specific techniques used for the direct or indirect restoration of endodontically treated teeth is dictated by the volume of the preserved hard dental structure, the inclination of the tooth in the alveolus, the occlusal forces exerted, the aesthetic requirements of the tooth and the type of restoration [7-9]. If in the past the devices cast from various metal alloys were used[10], nowadays modern anchorage elements such as prefabricated posts from titanium or fiberglass posts are widely used [11]. The length of time required for the preparation and application of the respective devices is an important element in everyday practice that guides the practitioner in selecting a specific type of device, but the resistance to mechanical stress and the reliability of the chosen system should not be neglected [12]. Unlike the dental pulp, the materials that will fill an endodontically treated root present a defined rigidity that results in the production of unnatural stresses and deformations [5] at the tooth. Different types of materials induce varying stresses, strains and deformations on the restored teeth. Based on the property of the materials, the mechanical behavior of a device can be assessed by FEM [13]. Deformation is defined as the transformation or modification of a body from one configuration to another [14], and by strain we mean the variation of dimensions in the vicinity of a point of the studied body, following the application of some stresses [15]. Many *in vitro* studies have been performed based on finite element analysis [16-20], but a consistent conclusion could not be established. The results of the present study shed further light on the stress resistance of endodontically treated teeth restored with three types of posts, which are covered with two different types of crowns. Other published studies have also analyzed the mechanical behavior in the case of performing abutment restorations with devices cast from metal alloys [12,21,22], gold [12,21,23], carbon fiber posts [21,23,24], fiberglass post [12,22-27], titanium [12,22,27], stainless steel [23,25-27]. In the respective studies, the abutments were covered by all-ceramic [21,22,27] or gold crowns [24,26].

A recent study [18] was performed applying a force of 100N, with an inclination of 135°, on monolithic zirconium oxide crowns cemented on restored abutments with cast posts, fiberglass posts, titanium posts or zirconium oxide posts, concluded that the best force distribution was achieved when using fiberglass posts, where the maximum stress occurred between the crown and the enamel-cementum junction.

The specialized literature has numerous recent studies [28-36] conducted on different types of posts used to increase the strength of restorations on endodontically treated teeth.

CONCLUSIONS

1. The use of FEM is an effective method for in vitro testing of the behavior of various types of devices used to increase the strength of restorations

on endodontically treated teeth. 2. When experimentally applying a force of 350N, the behavior of the analyzed systems was not identical. 3. The presence of zirconium oxide crowns generally produces less valuable stresses and deformations at the level of the components. 4. Regarding the devices used, the stress and strain values are lowest when using fiberglass posts, followed closely by cast post and far behind by titanium prefabricated post. The differences are given both by their specific design and by the materials from which they are made. 5. In all simulated situations, the limit values of stresses and strains are at the tooth root, which is susceptible to fracture in case of parafunctional forces, followed by the 3 devices themselves and the covering crowns, which are the least mechanically requested.

TABLE 1. Simulation results in the case of using cast post covered by INTEGRAL CERAMIC crown

	Total deformation, mm	Directional deformation X, mm	Directional deformation Y, mm	Directional deformation Z, mm	Equivalent strain, -	Maximum principal strain, -	Minimum principal strain, -	Maximum tangential strain, -	Normal elastic strain X, -	Normal elastic strain Y, -	Normal elastic strain Z, -
Minimum	0	-0,105	2,13e-3	-5,9e-2	2,02e-8	-1,59e-5	3,37e-5	2,83e-8	-4,28e-3	-2,75e-3	-7,74e-3
Maximum	0,112	2,13e-3	2,62e-2	1,99e-2	1,42e-2	9,25e-3	-8,15e-3	1,29e-2	4,68e-3	2,54e-3	7,53e-3
Minimum on	Root	Crown	Root	Crown	Root	Cast post	Root				
Maximum on	Crown	Cast post	Crown		Root		Cast post	Root			

	Tangential strain XY, -	Tangential strain YZ, -	Tangential strain XZ, -	Equivalent stress, MPa	Maximum principal stress, MPa	Minimum principal stress, MPa	Maximum tangential stress, MPa	Normal stress X, MPa	Normal stress Y, MPa	Normal stress Z, MPa	Tangential stress XY, MPa	Tangential stress YZ, MPa	Tangential stress XZ, MPa
Minimum	-4,4e-3	-8,69e-3	-6,23e-3	2,08e-4	-38,6	-299	1,18e-4	-161	-104	-271	-97,7	-39,6	-71
Maximum	8,32e-3	4,63e-3	6,48e-3	291	190	51,1	159	151	69,2	109	67,1	75,4	55,1
Minimum on	Root				Cast post		Root	Cast post					
Maximum on	Root			Cast post									

TABLE 2. Simulation results in the case of using cast post covered by ZIRCONIA crown

	Total deformation, mm	Directional deformation X, mm	Directional deformation Y, mm	Directional deformation Z, mm	Equivalent strain, -	Maximum principal strain, -	Minimum principal strain, -	Maximum tangential strain, -	Normal elastic strain X, -	Normal elastic strain Y, -	Normal elastic strain Z, -
Minimum	0	-8,38e-2	-1,76e-3	-4,4e-2	1,9e-8	-2,22e-5	-6,42e-3	2,66e-8	-3,8e-3	-1,85e-3	-5,84e-3
Maximum	8,89e-2	1,9e-3	1,91e-2	1,51e-2	1,08e-2	7,38e-3	4,01e-5	9,74e-3	3,93e-3	2,32e-3	5,82e-3
Minimum on	Root	Crown	Root	Crown	Root	Cast post	Root				
Maximum on	Crown	Cast post	Crown		Root						

	Tangential strain XY, -	Tangential strain YZ, -	Tangential strain XZ, -	Equivalent stress, MPa	Maximum principal stress, MPa	Minimum principal stress, MPa	Maximum tangential stress, MPa	Normal stress X, MPa	Normal stress Y, MPa	Normal stress Z, MPa	Tangential stress XY, MPa	Tangential stress YZ, MPa	Tangential stress XZ, MPa
Minimum	-3,78e-3	-6,95e-3	-5,55e-3	1,95e-4	-90,3	-779	1,1e-4	-405	-247	-674	-286	-108	-168
Maximum	6,04e-3	4,2e-3	4,85e-3	709	598	42,9	398	414	141	213	216	154	113
Minimum on	Cast post	Root			Cast post		Root	Cast post					
Maximum on	Root												

TABLE 3. Simulation results in the case of using fiberglass post covered by INTEGRAL CERAMIC crown

	Total deformation, mm	Directional deformation X, mm	Directional deformation Y, mm	Directional deformation Z, mm	Equivalent strain, -	Maximum principal strain, -	Minimum principal strain, -	Maximum tangential strain, -	Normal elastic strain X, -	Normal elastic strain Y, -	Normal elastic strain Z, -
Minimum	0	-8,99e-2	-1,81e-3	-5,26e-2	3,94e-9	4,67e-10	-9,05e-3	5,48e-9	-2,12e-3	-1,07e-3	-7,77e-3
Maximum	2,81e-2	-2,44e-2	8,12e-3	-6,1e-3	1,03e-3	4,77e-4	-3,87e-9	1,19e-3	9,89e-5	6,75e-5	-3,48e-4
Minimum on	Crown	Root	Crown	Root	Crown				Pivot	Crown	
Maximum on	Root	Crown	Root		Crown	Fiberglass post	Crown			Fiberglass post	Crown

	Tangential strain XY, -	Tangential strain YZ, -	Tangential strain XZ, -	Equivalent stress, MPa	Maximum principal stress, MPa	Minimum principal stress, MPa	Maximum tangential stress, MPa	Normal stress X, MPa	Normal stress Y, MPa	Normal stress Z, MPa	Tangential stress XY, MPa	Tangential stress YZ, MPa	Tangential stress XZ, MPa
Minimum	-3,8e-3	-4,36e-3	-4,75e-3	4,05e-5	-49,4	-262	2,28e-5	-151	-78	-175	-65,7	-75,4	-38,8
Maximum	2,4e-6	5,83e-3	5,95e-3	231	254	34,4	133	83,3	112	158	31,4	37,9	103
Minimum on	Fiberglass post		Crown		Fiberglass post		Crown	Fiberglass post					
Maximum on	Crown		Fiberglass post										

TABLE 4. Simulation results in the case of using fiberglass post covered by ZIRCONIA crown

	Total deformation, mm	Directional deformation X, mm	Directional deformation Y, mm	Directional deformation Z, mm	Equivalent strain, -	Maximum principal strain, -	Minimum principal strain, -	Maximum tangential strain, -	Normal elastic strain X, -	Normal elastic strain Y, -	Normal elastic strain Z, -
Minimum	0	-7,93e-2	-1,73e-3	-4,24e-2	3,93e-9	4,65e-10	-9,02e-3	5,46e-9	-2,64e-3	-1,06e-3	-7,72e-3
Maximum	8,66e-2	1,4e-3	2,95e-2	2,09e-2	1,1e-2	5,86e-3	-3,86e-9	1,15e-2	1,45e-3	1,96e-3	4,09e-3
Minimum on	Crown	Root	Crown	Root	Crown				Fiberglass post	Crown	Fiberglass post
Maximum on	Root	Crown	Root		Crown	Fiberglass post		Crown		Fiberglass post	Crown

	Tangential strain XY, -	Tangential strain YZ, -	Tangential strain XZ, -	Equivalent stress, MPa	Maximum principal stress, MPa	Minimum principal stress, MPa	Maximum tangential stress, MPa	Normal stress X, MPa	Normal stress Y, MPa	Normal stress Z, MPa	Tangential stress XY, MPa	Tangential stress YZ, MPa	Tangential stress XZ, MPa
Minimum	-3,65e-3	-3,89e-3	-4,71e-3	4,04e-5	-42,4	-476 MPa	2,27e-5	-188	-89,4	-440	-63,2	-67,4	-132
Maximum	2,33e-3	5,89e-3	6,94e-3	429	297 MPa	44,6	228	101	116	193	27,3	71,4	120
Minimum on	Fiberglass post		Crown		Root		Crown	Fiberglass post		Root	Fiberglass post		Root
Maximum on	Crown		Fiberglass post	Root	Fiberglass post		Root	Fiberglass post			Root		Fiberglass post

TABLE 5. Simulation results in the case of using prefabricated post from titanium covered by INTEGRAL CERAMIC crown

	Total deformation, mm	Directional deformation X, mm	Directional deformation Y, mm	Directional deformation Z, mm	Equivalent strain, -	Maximum principal strain, -	Minimum principal strain, -	Maximum tangential strain, -	Normal elastic strain X, -	Normal elastic strain Y, -	Normal elastic strain Z, -
Minimum	0	-0,14	-2,11e-3	-7,04e-2	4,31e-7	-8,04e-5	-1,04e-2	4,97e-7	-7,44e-3	-2,33e-3	-9,16e-3
Maximum	0,15	1,04e-3	3,85e-2	2,61e-2	3,36e-2	3,58e-2	1,69e-5	4,57e-2	5,7e-3	1,93e-3	2,64e-2
Minimum on	Root	Crown	Root	Crown	Root						
Maximum on	Crown	Root	Crown		Root						

	Tangential strain XY, -	Tangential strain YZ, -	Tangential strain XZ, -	Equivalent stress, MPa	Maximum principal stress, MPa	Minimum principal stress, MPa	Maximum tangential stress, MPa	Normal stress X, MPa	Normal stress Y, MPa	Normal stress Z, MPa	Tangential stress XY, MPa	Tangential stress YZ, MPa	Tangential stress XZ, MPa
Minimum	-1,04e-2	-4,46e-3	-3,47e-2	4,11e-3	-109	-432	2,07e-3	-296	-149	-291	-88,1	-70,6	-144
Maximum	9,19e-3	7,88e-3	5,44e-3	347	397	66,9	190	185	118	318	74,6	62,7	163
Minimum on	Root				Prefabricated post from titanium		Root	Prefabricated post from titanium					Root
Maximum on	Root					Prefabricated post from titanium	Root	Prefabricated post from titanium		Root	Prefabricated post from titanium		

TABLE 6. Simulation results in the case of using prefabricated post from titanium covered by ZIRCONIA crown

	Total deformation, mm	Directional deformation X, mm	Directional deformation Y, mm	Directional deformation Z, mm	Equivalent strain, -	Maximum principal strain, -	Minimum principal strain, -	Maximum tangential strain, -	Normal elastic strain X, -	Normal elastic strain Y, -	Normal elastic strain Z, -
Minimum	0	-0,126	-2,04e-3	-6,04e-2	4,37e-7	-1,98e-5	-1,46e-2	5,04e-7	-7,91e-3	-2,87e-3	-8,99e-3
Maximum	0,133	1,01e-3	3,35e-2	2,35e-2	3,52e-2	3,42e-2	5,07e-6	4,88e-2	5,95e-3	1,79e-3	2,15e-2
Minimum on	Root	Crown	Root	Crown	Root	Prefabricated post from titanium	Root				
Maximum on	Crown	Root	Crown		Root						

	Tangential strain XY, -	Tangential strain YZ, -	Tangential strain XZ, -	Equivalent stress, MPa	Maximum principal stress, MPa	Minimum principal stress, MPa	Maximum tangential stress, MPa	Normal stress X, MPa	Normal stress Y, MPa	Normal stress Z, MPa	Tangential stress XY, MPa	Tangential stress YZ, MPa	Tangential stress XZ, MPa
Minimum	-3,8e-3	-4,36e-3	-4,75e-3	4,05e-5	-49,4	-262	2,28e-5	-151	-78	-175	-65,7	-75,4	-38,8
Maximum	2,4e-6	5,83e-3	5,95e-3	231	254	34,4	133	83,3	112	158	31,4	37,9	103
Minimum on	Root				Prefabricated post from titanium		Root	Prefabricated post from titanium					Root
Maximum on	Root			Prefabricated post from titanium								Crown	Prefabricated post from titanium

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