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# Comparative analysis of stress and deformation distribution in implant-supported telescopic systems made of different materials

## Uporedna analiza distribucije pritiska i deformacije kod implantno-nošenih teleskop sistema izrađenih od različitih materijala

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### Abstract

**Background/Aim.** In implant prosthetics, there is an increasing use of materials that, with their mechanical characteristics, can alleviate the negative consequences of implant stress. The aim of this study was to conduct a comparative analysis of stress distribution and deformation of implant-supported telescopic systems and surrounding structures made of different materials using the finite element method. **Methods.** The 3D finite element models were prepared using the SolidWorks program (SolidWorks 2018, Concord, MA, USA). Two models of telescopic crowns with the characteristics of polyetheretherketone (PEEK) polymer and cobalt-chromium (Co-Cr) alloy faceted with feldspar ceramics were used. The models were loaded with an axial force of 150 N in the region of the central *fossa.* The analysis of stress and strain distribution was performed by the finite element method in the Ansys software (ANSYS Workbench 16; Ansys Inc., Pittsburg, PA, USA). **Results.** Implant-supported telescopic crowns made of PEEK polymer significantly reduced stress in the implant and abutment neck area compared to the conventional Co-Cr crown veneered ceramic. At the level of bone structure, both models showed a concentration of stress at the level of the cortical bone, while the trabecular bone was significantly less exposed to stress. Under the same conditions, the degree of deformation of the secondary telescopic crown was more pronounced in models with PEEK polymer characteristics. **Conclusion.** Owing to their mechanical characteristics, PEEK polymers can be the materials of choice in the fabrication of superstructures on implants. Given that this *in vitro* study was accompanied by limitations, further research is needed to confirm the superior role of PEEK material in implant prosthetics.

**Key words:**
**cobalt; chromium; computer-aided design; crowns; dental materials; dental stress analysis; polymers.**

### Apstrakt

**Uvod/Cilj.** U implantoprotetici se sve više koriste materijali koji svojim mehaničkim karakteristikama mogu ublažiti negativne posledice pritiska implantata. Cilj rada bio je da se sprovede uporedna analiza distribucije pritiska i deformacije implantno-nošenih teleskop kruna i okolnih struktura, izrađenih od različitih materijala, korišćenjem metode konačnih elemenata. **Metode**. Korišćenjem programa SolidWorks (SolidWorks 2018, Concord, MA, USA) pripremljeni su 3D modeli konačnih elemenata. Korišćena su dva modela teleskop kruna sa karakteristikama polietereterketon (PEEK) polimera i kobalt-hrom (Co-Cr) legure, fasetirane keramikom od feldspara. Modeli su bili opterećeni aksijalnom silom od 150 N u predelu centralne fose. Analiza distribucije pritiska i deformacije sprovedena je metodom konačnih elemenata u Ansys programu (ANSYS Workbench 16; Ansys Inc., Pittsburg, PA, USA). **Rezultati**. Implantno-nošene teleskop krune izrađene od PEEK polimera značajno su smanjivale pritisak u zoni vrata implantata i suprastrukture u poređenju sa konvencionalnom Co-Cr krunom fasetiranom keramikom. Na nivou koštane strukture, oba modela pokazala su koncentraciju pritiska na nivou kortikalne kosti, dok je trabekularna kost bila značajno manje izložena pritisku. Pri istim uslovima, stepen nastale deformacije sekundarne teleskop krune bio je viši kod modela sa karakteristikama PEEK polimera. **Zaključak**. Zahvaljujući mehaničkim karakteristikama, PEEK polimeri mogu biti materijali izbora u izradi suprakonstrukcija na implantatima. Kako je prezentovana *in vitro* studija praćena ograničenjima, neophodna su dalja istraživanja koja bi potvrdila superiornu ulogu PEEK materijala u implantoprotetici.

**Ključne reči:**
**kobalt; hrom; kompjuterski podržan dizajn; zub, kruna; stomatološki materijali; stomatološki stres, analiza; polimeri.**

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## Introduction

The telescopic crowns represent the culmination of biological and esthetic prosthetic rehabilitation. In some circumstances, depending on the layout of the carrier and the degree of resorption of bone tissue, as well as the possibility of later repair and proper hygiene, the telescopic crown is the only therapeutic solution. Owing to some advantages, telescopic systems extend the life of abutment teeth compared to other prosthetic restorations [1]. The telescope system consists of an inner (primary) and outer (secondary) crown. Classical cylindrical telescopes function on the principle of friction, although the jamming effect, which occurs with small movements of the prosthesis, also plays an important role in retention [2].

Three double crown systems are used in implant prosthetics: classical telescopic crowns, galvanic telescopes, and telescopes with additional retention elements. Some authors recommend that the primary crowns of implant-supported double crowns be slightly conical (1 °–2 °) to avoid imprinting and laboratory errors, which can make it difficult to place and remove the supraconstruction [3]. These intraoral inaccuracies can lead to a feeling of discomfort in the patient and an increase in stress at the implant level. In the case of taking care of telescopes whose carriers are natural teeth, due to the orthodontic movement of the same, the discomfort disappears after a few days. However, this compensatory mechanism is lacking in osseointegrated implants, which cannot be moved orthodontically and could result in permanent patient discomfort and relatively rapid implant loss [2].

In implant prosthetics, the use of materials that can alleviate the negative consequences of implant stress with their mechanical characteristics and provide comfort to patients is increasing. In that sense, polyetheretherketone (PEEK) polymers are being increasingly used due to their mechanical and biological characteristics. PEEK materials are basically semicrystalline linear polycyclic aromatic polymers. Young's modulus of elasticity and tensile properties are close to human bone, enamel, and dentin. At the same time, PEEK polymer is resistant to various nontoxic and biocompatible chemical agents [4]. It is stable at high temperatures (during the sterilization process) and resistant to wear [5].

Analysis of the influence of mechanical characteristics of materials on the distribution of stress on individual intraoral structures *in vitro* is often expensive and time-consuming [6, 7]. One of the methods that can supplement or replace such research is a computer simulation, such as the finite element method (FEM).

The aim of this study was to conduct a comparative analysis of stress distribution and deformation of the secondary crown, implants, and surrounding bone in implant-supported telescopic crowns made of PEEK polymer and cobalt-chromium (Co-Cr) alloy veneered with ceramics using the FEM.

## Methods

The first step in the research was the formation of 3D models necessary for the analysis. Using conical beam computed tomography (CBCT), a 3D image of the lower jaw in the region of the second premolar on the right side was made. The cross-section in the transverse plane was analyzed, and the contour of the bone cross-section of that region was reconstructed using the Corel draw vector graphics program. The resulting image was then extruded in the z-axis, using the appropriate Fusion 360-Autodesk program, creating a 3D model of the mandibular segment with a mesiodistal diameter of 10 mm. The bone was modeled so that the trabecular bone formed a nucleus surrounded by a layer of compacta. The dimensions of the trabecular bone were 9 mm in the laterolateral direction and 14 mm in the craniocaudal direction. The thickness of the compact part of the bone averaged 1.5 mm.

The one-piece dental implant model was designed using the program SolidWorks 2018 (Concord, MA, USA). The dimensions of the implant were 14.5 × 5 mm, with a platform height of 1.5 mm, a thread pitch of 0.9 mm, and a depth of 0.2 mm. The analysis was focused on the secondary crown and, therefore, the abutment and the implant were combined into one whole. After that, the one-part model of the implant was processed in the SolidWorks program in which the virtual abutment milling was performed at an angle of 90 °.

Based on the abutment, a primary crown telescope 3 mm wide and 5 mm high was formed, with a half-groove width of 1 mm. Then, the virtual implantation of a one-piece model of the implant into a previously designed bone model was performed.

The secondary crown model was obtained by scanning the real model. Based on the obtained scan by reverse engineering, a solid model was created using the SolidWorks 2018 program. In the same program, the inside of the secondary crown was formed using the Cut option in order to make it congruent with the outer surface of the primary telescopic crown of the implant. On average, the crown was 9 mm high, 10.9 mm wide, and 3 mm thick.

Two experimental models were used in this study. The characteristics of a PEEK polymer were given to the first model (Figure 1a). In the case of the second model, the secondary crown was given the characteristics of Co-Cr alloy, 1 mm thick, faceted with feldspar ceramics to the final morphological shape (Figure 1b).

**Fig. 1 − Experimental models: a) Model with polyetheretherketone (PEEK) characteristics; b) Model with cobalt-chromium alloy characteristics.**

*Mechanical characteristics of materials*

All materials used in the study were considered homogeneous, linear, and isotropic. The mechanical properties of the materials used in the study were collected from the published literature [8–15] (Table 1). Young's modulus, Poisson's ratio, and density were used as material characteristics. Based on these features, a library of materials in the Ansys program was created, which was later used during the FEM analysis. The study was conducted under the assumption that the implant was completely osseointegrated.

*Loads and limitations*

A linear static structural simulation was performed using ANSYS Workbench 16.0 (Ansys, Inc.). It shows the relationship (deformation and stress) between the secondary telescopic crown, the implant-abutment, and the bone. The finite element models in the first experimental model consisted of 93,463 triangular elements and 159,100 nodes, while the second experimental model consisted of 97,985 triangular elements and 167,170 nodes. In this study, the implant was subjected to an axial static load of 150 N with an attack point of force in the immediate vicinity of the central *fossa* [16].

The contact conditions between the components of each model are clearly defined, with the bonded type of connection being mostly represented. The contact between the primary and secondary crown was defined as the frictional ratio, with a friction coefficient of 0.2 k (Tables 2 and 3).

**Results**

*Analysis of von Mises stress and deformation values of the secondary crowns*

After the analysis, it was noticed that the stress concentration of the secondary crown in the first model was located in the region of action of the attacking force, i.e., the zone of the central *fossa*, while in the second model, the highest stress concentration was in the zone of the marginal line. It was also notable that these stress values were somewhat lower in the secondary crown made of PEEK polymer compared to the secondary crown made of Co-Cr veneered with porcelain.

**Table 1**

**Mechanical properties of tested materials**

| Materials | Young's modulus (MPa) | Poisson's ratio | Density (g/cm$^3$) |
|---|---|---|---|
| Cortical bone | 13,700 | 0.3 | 1.85 |
| Trabecular bone | 1,370 | 0.3 | 0.9 |
| Ti-6Al-4V implant | 110,000 | 0.35 | 4.51 |
| Co-Cr alloy | 218,000 | 0.33 | 10 |
| Feldspar porcelain | 65,000 | 0.25 | 2.45 |
| PEEK Juvora | 5,591 | 0.36 | 1.3 |

**Ti-6Al-4V – titanium-aluminium-vanadium; Co-Cr – cobalt-chromium; PEEK – polyetheretherketone; MPa – megapascal.**

**Table 2**

**Contact between components in the first model**

| Cortical bone | Trabecular bone | Bonded |
|---|---|---|
| Cortical bone | implant | bonded |
| Trabecular bone | implant | bonded |
| Abutment | secondary crown | frictional |

**Table 3**

**Contact between components in the second model**

| Cortical bone | Trabecular bone | Bonded |
|---|---|---|
| Cortical bone | implant | bonded |
| Trabecular bone | implant | bonded |
| Abutment | secondary crown (Co-Cr) | frictional |
| Secondary crown (Co-Cr) | feldspar ceramics | bonded |

**Co-Cr – cobalt-chromium.**

The axial load was performed next to the central *fossa* of the secondary crown. Figure 2 shows the behavior of a secondary crown made of PEEK polymer at an axial load of 150 N. By analyzing the results of stress, it can be said that its highest concentration was localized on the outer surface of the secondary crown itself near the attack point of force. Most of the stress was amortized by the secondary crown or its surface layers. Therefore, the inner surface of the secondary crown was in the zone of minimal stress. That also reduced the transmission of stress to the implant (Figure 2a).

In the second model, the highest concentration of stress was localized in the zone of the marginal line, i.e., at the edge of the secondary crown (Figure 2b). It was also noticeable that these stress values were slightly higher in the secondary crown made of PEEK polymer compared to the secondary crown made of Co-Cr faceted with porcelain.

When it comes to deformation, it was most pronounced in both models in the region of action of the attacking force (Figure 3a). From the aspect of deformation intensity, higher values were present in the first model, which is in line with the lower values of the modulus of elasticity of the PEEK polymer (Figure 3 b).

*Analysis of von Mises stress and deformation values of the implant model*

At the implant level, in both examined models, the highest stress concentration can be seen in the area of the implant neck. However, the stress values differ significantly in the first and second models. In the first model with a secondary crown made of PEEK polymer, the amount of stress was almost twice as low as in the second model with a secondary crown made of Co-Cr alloy veneered with ceramics (Figures 4a and 4b). From the aspect of deformation, it was somewhat more pronounced in the first model (Figures 5a and 5b).

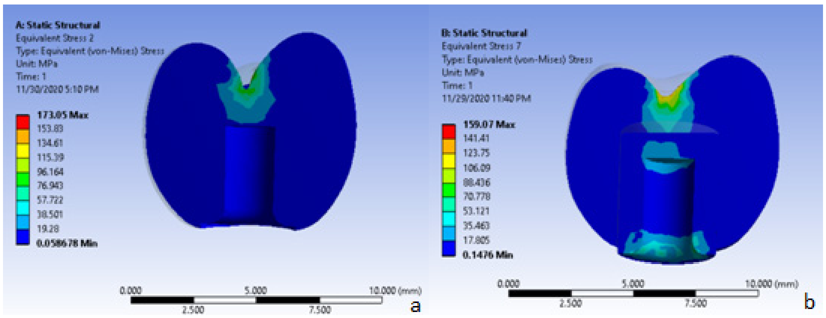


**Fig. 2 − Sagittal section views for stress distribution of crown: a) First experimental model; b) Second experimental model.**

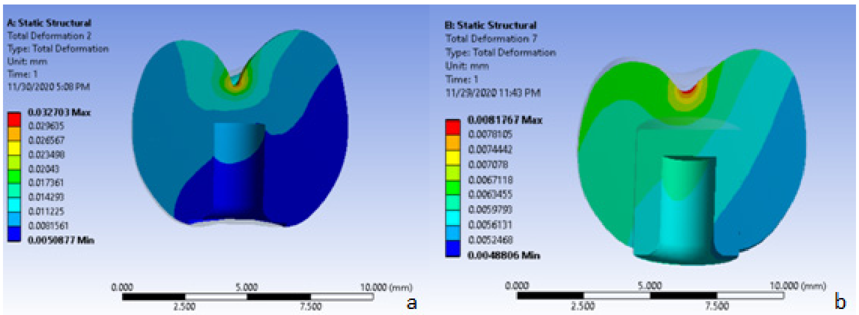


**Fig. 3 − Sagittal section views for deformation of the crown: a) First experimental model; b) Second experimental model.**

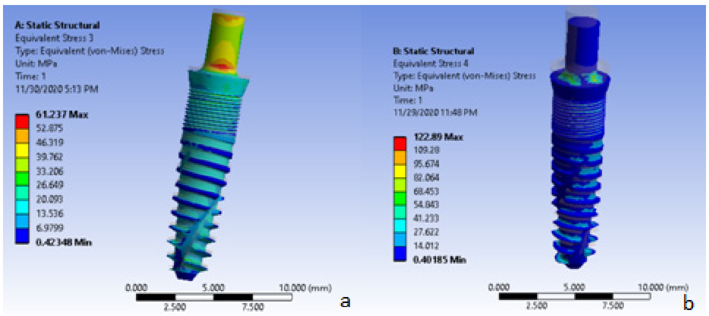


**Fig. 4 − Stress distribution of implant: a) First experimental model; b) Second experimental model.**

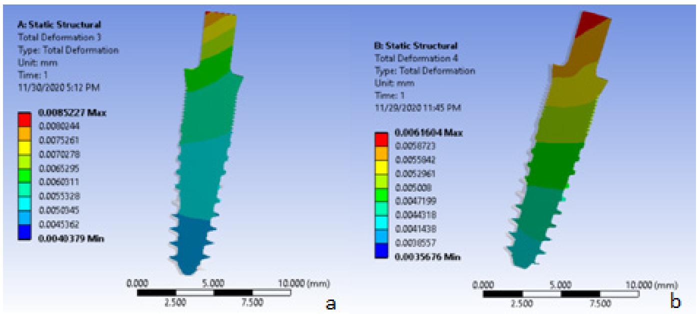


**Fig. 5 – Sagittal section views for deformation of implant: a) First experimental model; b) Second experimental model.**

*Analysis of von Mises stress and deformation values of the bone*

Analysis of stress at the level of bone tissue showed that most of the stress is accepted by the cortical bone next to the implant neck. At the same time, significant differences in stress values were not observed between the experimental models (Figure 6). Deformation of the cortical bone does not show significant differences in both examined models (Figure 7).

At the level of trabecular bone stress, intensity is significantly lower than in cortical bone. Such findings are a consequence of the acceptance of most of the stress by the cortical bone, and a smaller amount of stress is transferred to the trabecular bone. However, the analysis of stress values at the level of the spongy bone showed significantly lower values in the first experimental model, where the PEEK secondary telescopic crown was used (Figure 8). The analysis of spongy bone deformation does not show significant differences between the examined models (Figure 9).

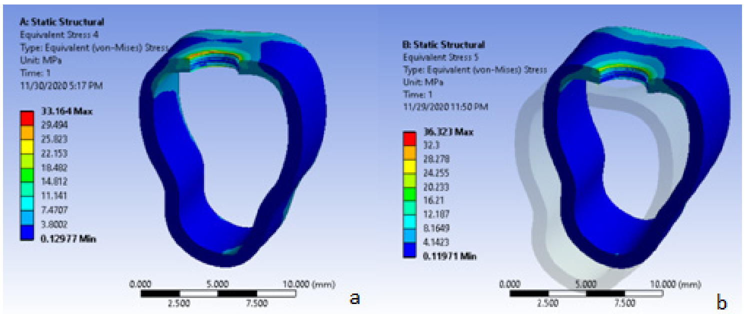


**Fig. 6 – Sagittal section views for stress distribution of cortical bone: a) First experimental model; b) Second experimental model.**

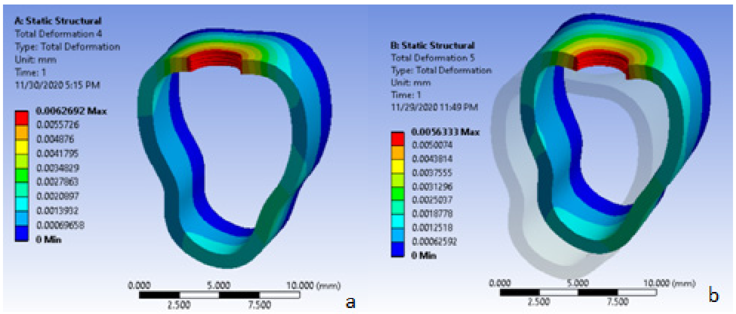


**Fig. 7 – Sagittal section views for deformation of cortical bone: a) First experimental model; b) Second experimental model.**

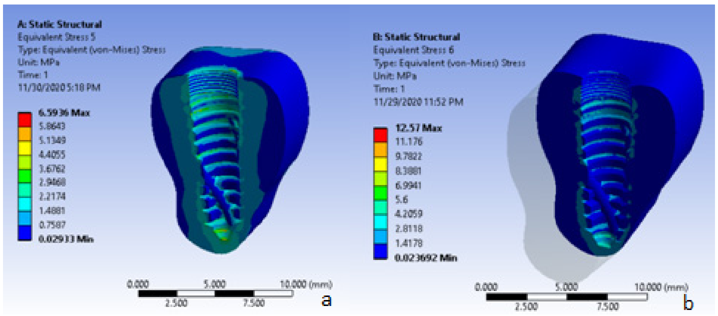


**Fig. 8 – Sagittal section views for stress distribution of spongy bone: a) Frst experimental model; b) Second experimental model.**

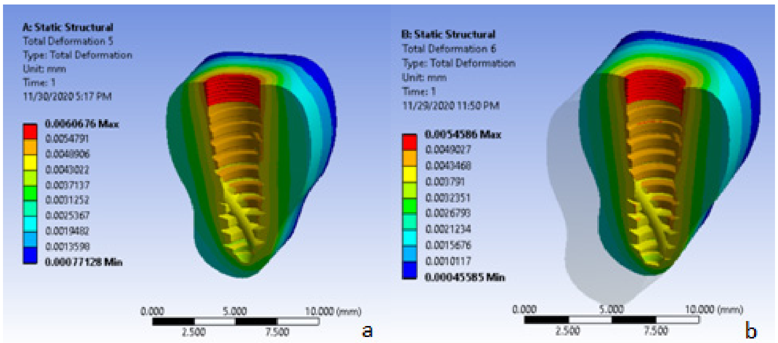


**Fig. 9 − Sagittal section views for deformation of spongy bone: a) First experimental model; b) Second experimental model.**

## Discussion

Tooth loss unequivocally requires prosthetic rehabilitation of the patient. It is believed that only properly performed prosthetic therapy can reduce the bone resorption that inevitably occurs after tooth loss [17]. For these reasons, this study aimed to examine the intensity of stress on the secondary telescopic crown, implant, and bone tissue, which develops when using different materials to make superstructures on implants. The research was conducted under the assumption that the used models were homogeneous, isotropic, and linearly elastic. However, it is known that there is no absolutely homogeneous and isotropic material in nature, so the use of mean values does not exclude the possibility of errors in the results of *in vitro* tests [18]. These facts represent some of the limiting factors of this study. In this study, an occlusal axial load of 150 N was used, which is the average value of the worrying forces produced in patients with implants [19]. However, *in vitro* conditions during the function of the stomatognathic system also develop extra-axial forces that can have a more detrimental effect on implants and prosthetic restorations. Accordingly, this could also be a limiting factor in this research.

When it comes to telescopes on implants, the frictional ratio of the primary and secondary crown gives additional freedom of movement, which reduces the stress on the implant itself. Some studies have confirmed that stress and cortical bone deformities are significantly less in implant-supported telescopic crowns than in certain superstructures on locators [20].

A special focus of this research was on PEEK polymer, which is more biocompatible and lighter than metal, so it represents its suitable alternative. Furthermore, PEEK polymer does not cause galvanic corrosion if it comes in contact with other metals in the mouth [21]. The results of our research indicate that secondary crowns made of PEEK provide significant stress adsorption and protection of surrounding structures from stress. These findings can be explained by a similar modulus of elasticity between the PEEK polymer and the bone structure, resulting in less stress on the bone and implant.

In a similar study, Tekin et al. [22] analyzed the distribution of stress and strain in fixed restorations made of PEEK polymers. The results of this study showed that the modulus of elasticity of PEEK material and bone is similar and that, in this way, the incoming forces are absorbed, and the stresses on the bone structures are minimized. It was also found that von Mises stresses on the PEEK crown were concentrated at the marginal end line, but the stress value was reduced at the abutment level. The results of our research show that at the level of implants, in both examined models, the highest concentration of stress is present in the area of the implant neck. At the same time, the value of stress was twice lower in the PEEK model compared to the model of Co-Cr alloy veneered with ceramic. The local concentration of stress on the secondary PEEK telescopic crown and its deformation reduce the transmission of stress to the primary crown and abutment. These findings indicate that the PEEK polymer can act as a stress absorber, protecting the surrounding structures from excessive stress. Zoidis and Papathanasiou [23] found that the PEEK crown did not make a significant difference in relation to the metal-ceramic one in terms of stress on bones and implants but that the use of the PEEK crown certainly reduced the stress on the abutment. Dashti et al. [24] found that PEEK crowns reduce stress on the abutment, as well as that the highest values of stress are observed in the zone of cortical bone around the neck of the implant. This fact indicates the adsorption of stress by the cortical bone and the reduction of stress transmission to the trabecular bone. The findings of this study support the results of our research.

El-Anwar et al. [25] concluded that the material from which the crown was made has a negligible effect on the distribution of forces on the cortical bone. Our study also showed that the values of stress that occur on the cortical bone during loading are very similar in both tested models.

Studies have shown that PEEK softens the effects of masticatory forces precisely because of its elasticity [26, 27]. The elasticity of this material is especially important in prosthetic restorations that are implant-worn, where, due to the lack of mechanoreceptors of the periodontium, the control of mastication is reduced in the absence of inhibitory mechanisms. Therefore, stress is more present in implant-compensated restorations than in natural dentition. Our research, along with available data from the literature, indicates that PEEK polymers will be a good alternative to metal alloys in the future.

## Conclusion

PEEK polymers reduce the distribution of stress at the level of implants, abutments, and trabecular bone. Owing to their mechanical characteristics, PEEK polymers can be the materials of choice in the fabrication of superstructures on implants. However, because this *in vitro* study has some limitations, further research is needed to confirm the superior role of PEEK material in implant prosthetics.

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