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The influence of the shock-absorbing restorative materials on the stress distributions of short dental implant rehabilitations

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Abstract. – OBJECTIVE: Polymer materials with shock-absorbing ability may offer better stress distribution with short dental implants (SDI). The present study aimed to evaluate the effect of abutment and crown materials on the stress distributions in short implant-prosthesis-complex (6 mm) and standard implant-prosthesis-complex (10 mm) using 3D finite element analysis (FEA).

MATERIALS AND METHODS: Two FEA models were designed to simulated single implant restoration of mandibular first molar, one each for short implant (6 mm) (Group S) and standard implant (10 mm) (Group C). In each group, two abutment materials were used, Polyetheretherketone (PEEK) and Zirconia (Zr), with two types of crowns, PEEK and Polymer-infiltrated ceramic-network (PICN). A vertical force of 200 N was applied to each central fossa. Stress distribution was evaluated via the von Mises stress analysis.

RESULTS: Using the PEEK abutment, the stress was better dispersed with PEEK crowns, as compared to PICN crowns. The stress was concentrated on the platforms of Ti-bases and the head and middle part of abutment screws. In zirconia abutment, the stress was greatly concentrated on the axial angle regions when placed with the PEEK crowns, while the stress was dispersed when placed with PICN crowns. The stress was concentrated on the connector regions of Ti-bases and the middle part of abutment screws. For implants, the stress was concentrated on the neck of the two implants, regardless of crown materials and abutment materials. The PEEK materials were found to be suitable for the hybrid-retained prostheses of SDI.

CONCLUSIONS: Our study indicates that the PEEK material is more suitable for the hybrid restorations of SDI. If the Zr abutment is used, the PICN crown would be better. Further, in-vivo clinical trials comparing these materials are needed to strengthen evidence.

Key Words:

Dental implant, Stress distribution, Shock-absorption ability, Polyetheretherketone, Polymer-infiltrated ceramic-network.

Abbreviations

FEA: finite element analysis; HPP: High performance polymers; PEEK: Polyetheretherketone; PICN: Polymer-infiltrated ceramic-network; SDI: Short dental implants; Zr: Zirconia.

Introduction

Dental implant rehabilitation in severely atrophic jaws still remains a challenge. Various bone augmentation techniques have been used to enhance bone volumes in atrophied ridges for placement of standard implants. However, the procedures are associated with limitations such as high cost, long treatment time, increased postoperative morbidity and increased risk of complications[1]. Alternatively, short dental implants (SDI) have been proposed in order to avoid bone augmentation, thereby reducing treatment time and associated complications.

The survival rates of SDI remain controversial. A number of clinical studies have documented that the survival rates of SDI are comparable to those of the standard implants[2,3]. On the contrary, some studies have reported a lower survival rate with SDI[4,5]. In a recent systematic review and meta-analysis, a time-dependent reduction in the survival rate of single-unit restoration with 6 mm SDI in the posterior area has been demonstrated.

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The review indicated that the short- and mid-term survival rates of SDI (6 mm) are similar to standard implants, whereas the long-term survival rates are lower[6]. Rossi et al[7] found that the marginal bone loss of SDI was lower than that of standard implants; however, SDI demonstrated a sudden loss of stability during the functional loading. The authors have postulated that loss of SDI may due to a fracture of supporting bone as a result of pathological overloading.

To prolong survival of implants, a correct transfer of occlusal force in the implant-prosthesis-complex and to the peripheral bone is important. Unlike natural teeth, osteointegration results in a rigid connection between the alveolar bone and dental implant. Thus, the occlusal forces are transmitted to the peri-implant bone directly without any shock-absorbing element[8]. As there is no possibility to create a periodontal ligament, the choice of the restorative material is the only way to create a shock-absorbing effect within the implant-prosthesis-complex.

A variety of materials are available for dental implant prostheses. Ceramic materials such as zirconia (Zr) and glass ceramic, has been widely used due to the high esthetics, excellent biocompatibility, however, these rigid materials may transmit excessive loads to the implant-prosthesis-complex, resulting in biological as well as technical complications[8-10]. High performance polymers (HPPs) are gaining popularity for the fabrication of dental restorations. Compared to ceramics, HPPs have a lower elastic modulus, and are believed to offer greater shock-absorbing effect that might lead to reduced load transmission and micro-movements between the implant components[11,12].

Due to the atrophic alveolar bones, the SDI are always associated with high crown-to-implant ratios leading to unfavorable occlusal forces. In this situation, a long crown supported by a prefabricated abutment is prone to result in a series of technique complications, such as loosening of crown or abutment screw[13]. Recently, a modified hybrid design has been introduced, in which a CAD/CAM costumer-made abutment is bonded to titanium base, and screwed to the implant, then a crown is cemented on it[14]. This costumer-made hybrid abutment could be an effective way to avoid those technique complications resulted by high crown-to-implant ratios.

Several types of HPPs are already available for clinical use for hybrid-abutments and crowns. Polymer-infiltrated ceramic-network (PICN) consists of 86 wt% ceramic and 14 wt% polymer[15]. Several studies[16,17] report that PICN is a promising material in implant prosthesis restorations. Polyetheretherketone (PEEK), a synthetic polymer material with an elastic modulus similar to human bone, has attracted much attention in dental implant restorations[18]. A series of studies[19-21] have focused on the application of PEEK in dental implant, abutment, and even crown and frameworks. However, the literature on the applications of PICN and PEEK for SDI restorations is scarce. It is unclear if these shock-absorbing materials have a beneficial role in restorations of SDI.

It is difficult to evaluate the shock-absorbing ability of restorative materials through regular mechanical studies. Finite element analysis (FEA) is a virtual biomechanical method to detect stress behaviors within a structure[22,23]. It could be used to evaluate the shock-absorbing ability of restorative materials and to study its effect on the implant-prosthesis-complex.

Thus, the present study aimed to evaluate the effects of different abutment and crown materials on the stress distributions in SDI (6 mm) restorations and the respective peripheral bone compared with standard implants (10 mm) restorations using 3D-FEA. Two abutment materials were evaluated: PEEK and Zr; while two crown materials were evaluated: PEEK and PICN. The null hypothesis was that: 1) the stress distribution is similar in the implant-prostheses-complexes between PEEK abutment and Zr abutments; 2) the stress distribution is similar in the implant-prostheses-complexes between the cement of PEEK crown and PICN crown.

Materials and Methods

Two 3D models were designed (Autodesk 3D, S. Rafael, CA, USA) to simulate different clinical situations of single implant restoration of the mandibular first molar. One was restored by SDI (6 mm) (Group S) (Figure 1A); while another was restored with a standard implant (10 mm) (Group C) (Figure 1B).

In group S, a supporting bone was constructed with a height of 12 mm, on which the thickness of cortical bone was set at 2.0 mm and the internal part was set as cancellous bone. An implant of 4.0 mm in diameter and 6.0 mm in length was placed into the bone model. Then, a simulated titanium (Ti)-base of 5.0 mm in height was inserted in the implant, a customer-made abutment of 10 mm in

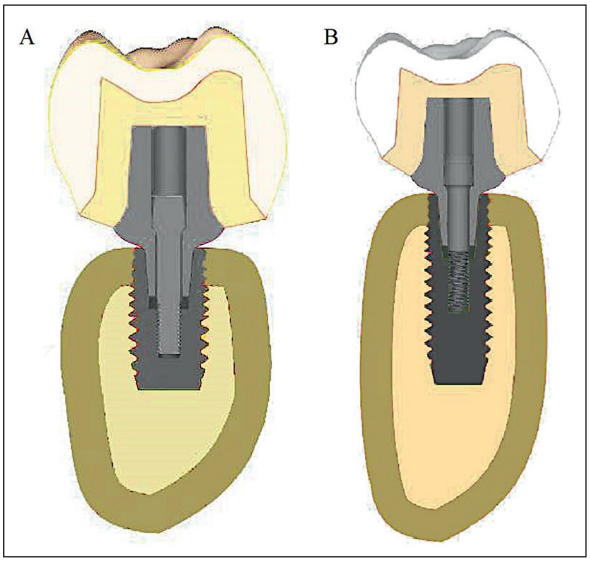

Figure 1. Schematic geometry of the models of hybrid designed restorations restoring the left mandibular first molar: (**A**): the SDI; (**B**) the standard implant.

height was placed onto the Ti-base, followed by a placement of a crown of 2 mm in thickness. In group C, a supporting bone was constructed with a height of 20 mm, on which the thickness of cortical bone was set at 2.0 mm and the internal part was set as cancellous bone. An implant of 4.0 mm in diameter and 10.0 mm in length was placed into the bone model. Then, a simulated Ti-base of 5.0 mm in height was inserted to the implant, a customer-made abutment of 6 mm in height was placed onto the Ti-base, followed by a placement of a crown of 2 mm in thickness.

In the two models, the cement space between the custom-made abutment and Ti-base and between the abutment and crown set at 30 µm. In each group, two types of abutment materials were used, PEEK and Zr, along with two types of crown materials, PEEK and PICN.

Table I. Total number of nodes and elements for models.

Model	Elements	Nodes
Group S	795766	195740
Group C	913470	218737

After modeling, all geometries were exported to discretization in the finite element software (Simlab 2017, Altair Engineering Inc., Troy, MI, USA) for preprocessing to obtain meshes of tetrahedral parabolic solid elements for all structures. The nodes and elements of the two models were demonstrated in Table I. It was assumed that all the materials used were isotropic, homogeneous, and linearly elastic as specified by Young's modulus and Poisson's ratio. Referred material properties are presented in Table II[24]. The surface between each component was restricted. In each group, 200 N of vertical load was applied to the central fossa of crown.

The processing analysis of the finite element analysis was performed using OptiStruct 2017 software (Altair Engineering Inc., Troy, MI, USA). The results were exported to the HyperView 2017 software (Altair Engineering Inc., Troy, MI, USA) to create maps stress on each component of the models. Von Mises analysis was used to assess the stress distribution in the implant-prosthesis-complexes and peripheral cortical bones.

Results

Different crown and abutment material combinations showed different stress distribution patterns in the two groups. The stress was mainly concentrated on the occlusal surface in each crown in the two groups. The stresses were more

Table II. Material properties.

Material	Young's Modulus (GPa)	Poissons Ratio
Cortical Bone	13.7	0.30
Cancellous Bone	1.37	0.30
Commercially Pure Titanium	110	0.35
Titamium Alloy	110	0.35
Resin cement	18.6	0.28
Zirconia	210	0.30
PEEK	3.5	0.36
PICN	30	0.23

PICN, Polymer-infiltrated ceramic-network; PEEK, Polyetheretherketone.

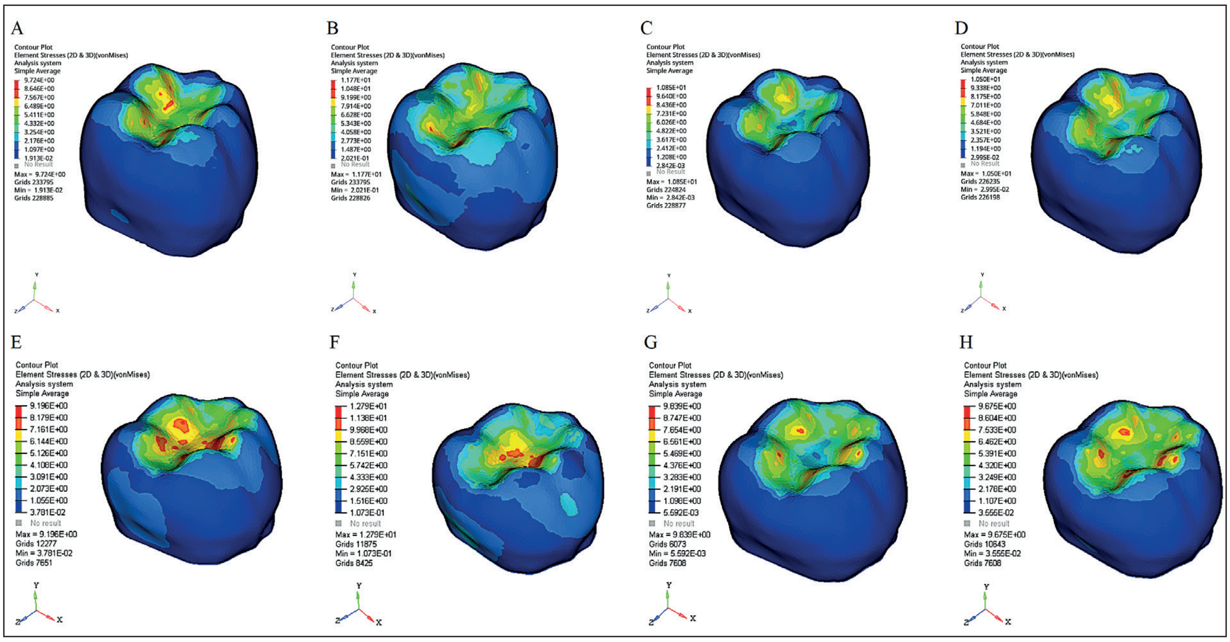

Figure 2. Distribution of stresses in crowns in the two groups. **A**, Distribution of stresses in crowns with PEEK crown and PEEK abutment in group S; **B**, Distribution of stresses in crowns with PICN crown and PEEK abutment in group S; **C**, Distribution of stresses in crowns with PEEK crown and zirconia abutment in group S; **D**, Distribution of stresses in crowns with PICN crown and zirconia abutment in group S; **E**, Distribution of stresses in crowns with PEEK crown and PEEK abutment in group C; **F**, Distribution of stresses in crowns with PICN crown and PEEK abutment in group C; **G**, Distribution of stresses in crowns with PEEK crown and zirconia abutment in group C; **H**, Distribution of stresses in crowns with PICN crown and zirconia abutment in group C.

evenly disturbed on the crowns of the Group S than the Group C (Figure 2). The stress dispersed to the axial surface on the crowns cemented to PEEK abutments (Figure 2A, B, E, F), compared to those cemented to the Zr abutments (Figure 2C, D, G, H). A more dispersed stress distribution was found on the PICN crowns cemented to PEEK abutment (PICN-PEEK) compared to the PEEK crown cemented to PEEK abutment (PEEK-PEEK) in both groups. The maximum stress values in the crown with different crown and abutment materials are presented in Table III. Overall, stress values were higher in Group S as compared to Group C, except for the PICN-PEEK combination wherein stresses were higher in Group C.

The stress distribution patterns varied in the abutments of different crown-abutment material combinations. The stress dispersed most evenly in the abutments of PEEK-PEEK combination (Figure 3A, E) while the stress was concentrated on the occlusal and cervical regions in the abutments of PICN-PEEK combination (Figure 3B,F) For PEEK-Zr combination, the stress was concentrated on the axial angles regions of the abutments (Figure 3C,G), and for

Table III. The maximum stress in the crowns in the two groups.

	Group S		**Group C**	
	PEEK abutment	**Zr abutment**	**PEEK abutment**	**Zr abutment**
PEEK crown	9.72	10.85	9.20	9.84
PICN crown	11.77	10.50	12.79	9.68

PICN, Polymer-infiltrated ceramic-network; PEEK, Polyetheretherketone; Zr, Zirconia.

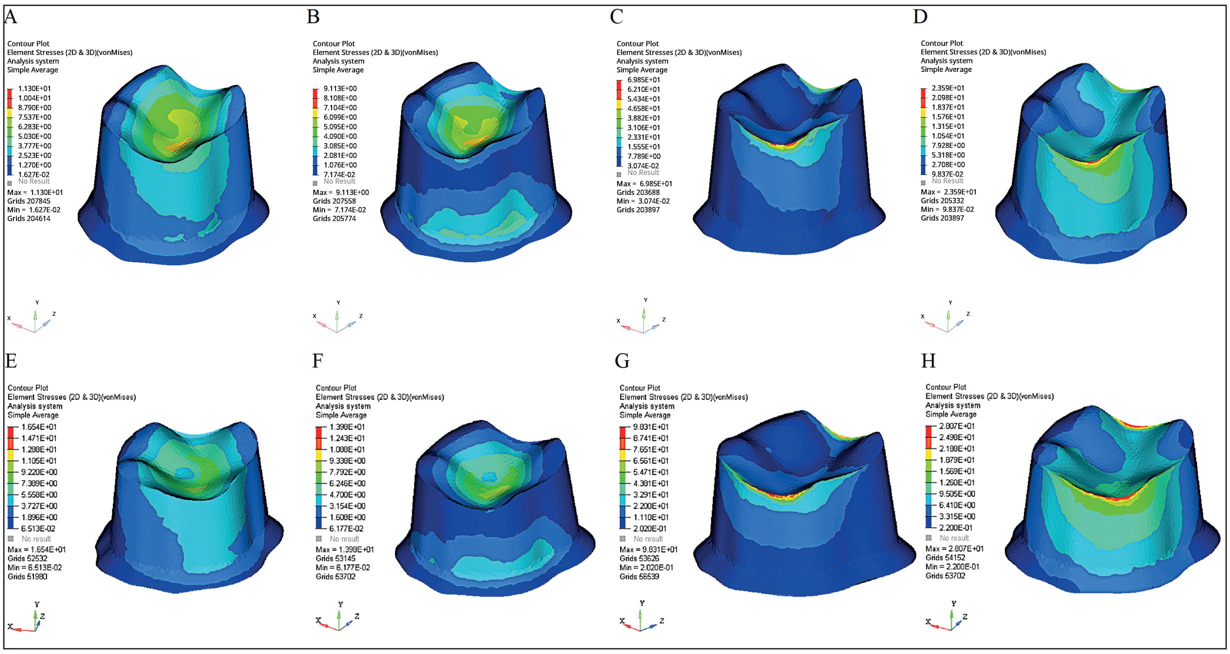

Figure 3. Distribution of stresses in abutment in the two groups. **A**, Distribution of stresses in abutment with PEEK crown and PEEK abutment in group S; **B**, Distribution of stresses in abutment with PICN crown and PEEK abutment in group S; **C**, Distribution of stresses in abutment with PEEK crown and zirconia abutment in group S; **D**, Distribution of stresses in abutment with PICN crown and zirconia abutment in group S; **E**, Distribution of stresses in abutment with PEEK crown and PEEK abutment in group C; **F**, Distribution of stresses in abutment with PICN crown and PEEK abutment in group C; **G**, Distribution of stresses in abutment with PEEK crown and zirconia abutment in group C; **H**, Distribution of stresses in abutment with PICN crown and zirconia abutment in group C.

PICN-Zr combination, the stress was dispersed in the abutment. The stress values are presented in Table IV. Group S had lower stress values for all material combinations. Least stress was noted with the PICN-PEEK combination while highest stress was seen with the PEEK-Zr combination.

The stress distributions on the Ti-bases were significantly affected by abutment materials regardless of the crown materials. In case of PEEK abutments, the stresses were concentrated on the platforms of the Ti-bases (Figure 4A, B, E, F), while in case of the Zr abutments, the stresses were concentrated at the connection parts (Figure 4C, D, G, H). Stress values are presented in Table V. The maximum stress was lower in group S as compared to group C for all combination of materials. Stress values were comparatively lower with Zr abutments as compared to PEEK abutments in both groups.

In case of the screws of the Ti-bases cemented to the PEEK abutments, the stress was concentrated on the head and middle parts of screws (Figure 5 A,B,E,F) while in case of those cemented to the Zr abutments, the stress was concentrated at the middle parts of screws (Figure 5C,D,G,H). Stress values

Table IV. The maximum stress in the abutments in the two groups.

	Group S		Group C	
	PEEK abutment	**Zr abutment**	**PEEK abutment**	**Zr abutment**
PEEK crown	11.30	69.85	16.54	98.31
PICN crown	9.11	23.59	13.98	28.07

PICN, Polymer-infiltrated ceramic-network; PEEK, Polyetheretherketone; Zr, Zirconia.

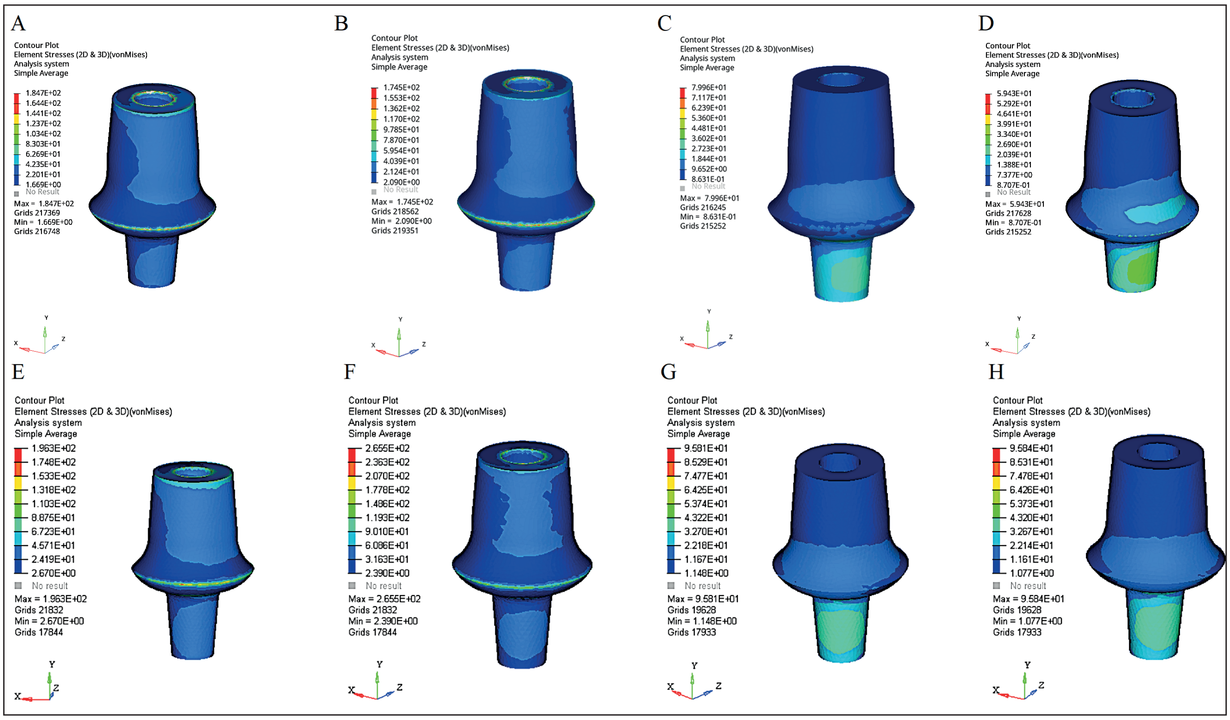

Figure 4. Distribution of stresses in Ti-bases in the two groups. **A**, Distribution of stresses in Ti-base with PEEK crown and PEEK abutment in group S; **B**, Distribution of stresses in Ti-base with PICN crown and PEEK abutment in group S; **C**, Distribution of stresses in Ti-base with PEEK crown and zirconia abutment in group S; **D**, Distribution of stresses in Ti-base with PICN crown and zirconia abutment in group S; **E**, Distribution of stresses in Ti-base with PEEK crown and PEEK abutment in group C; **F**, Distribution of stresses in Ti-base with PICN crown and PEEK abutment in group C; **G**, Distribution of stresses in Ti-base with PEEK crown and zirconia abutment in group C; **H**, Distribution of stresses in Ti-base with PICN crown and zirconia abutment in group C.

did not show much variation in the two groups and with different material combinations (Table VI)

Analyzing the stress distribution on implants, the stress was concentrated on the neck of implants and were dispersed along the screws for all different combinations (Figure 6). The maximum stresses were higher in group S than group C with little differences between different crown-abutment combinations (Table VII).

The stress distribution patterns of cortical bones were also similar with different crown-abutment material combinations (Figure 7). There were no major differences between the two groups and between different material combinations for the stress values (Table VIII).

Discussion

In the present study, the stress distribution patterns in the implant-prosthesis-complex were different with different crown-abutment material combinations. Thus, the null hypothesis was rejected.

Table V. The maximum stress of the Ti-bases in the two groups.

	Group S		Group C	
	PEEK abutment	**Zr abutment**	**PEEK abutment**	**Zr abutment**
PEEK crown	184.70	79.96	196.30	95.81
PICN crown	174.50	59.43	265.50	95.84

PICN, Polymer-infiltrated ceramic-network; PEEK, Polyetheretherketone; Zr, Zirconia.

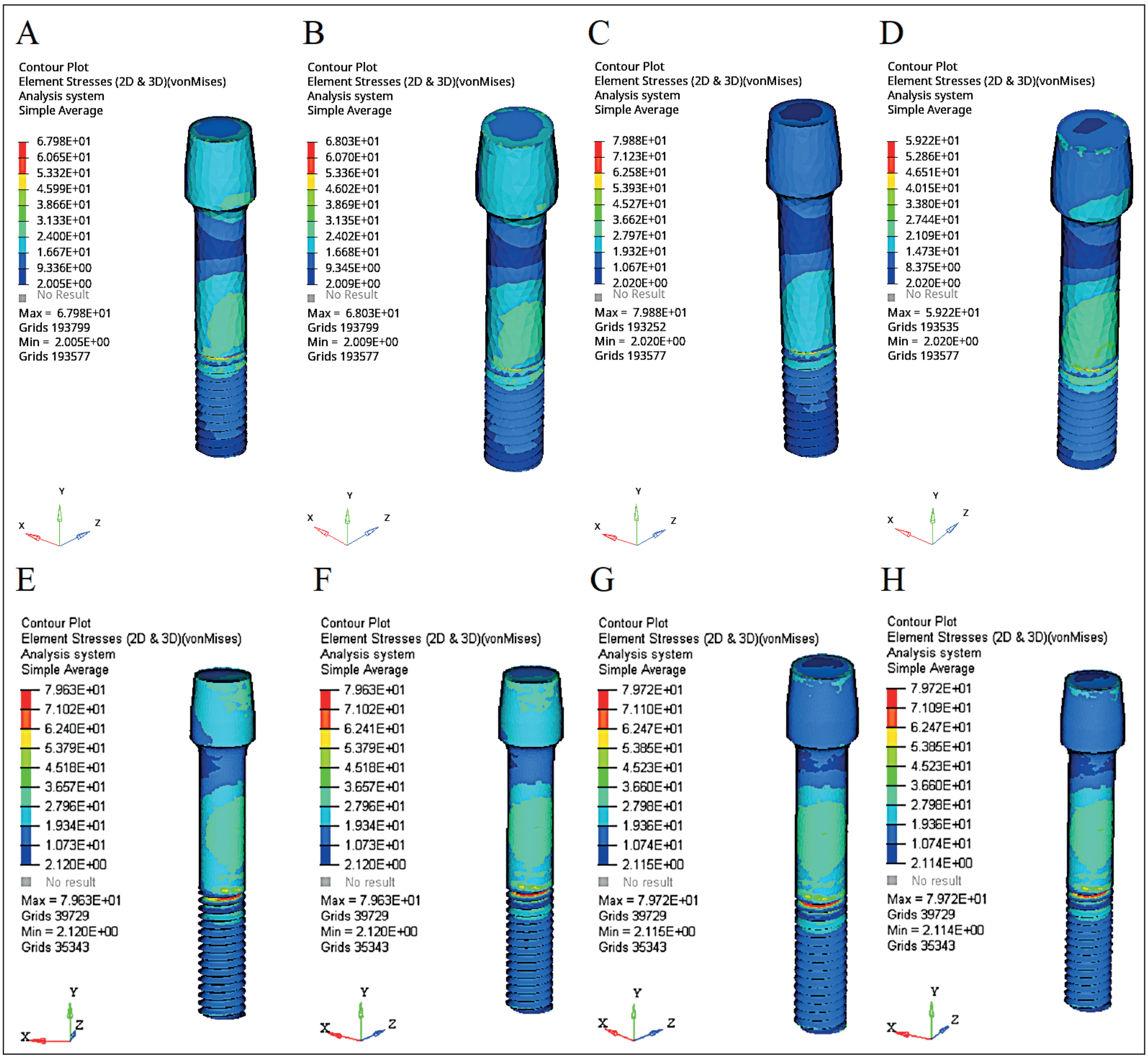

Figure 5. Distribution of stresses in screws in the two groups. **A**, Distribution of stresses in screw with PEEK crown and PEEK abutment in group S; **B**, Distribution of stresses in screw with PICN crown and PEEK abutment in group S; **C**, Distribution of stresses in screw with PEEK crown and zirconia abutment in group S; **D**, Distribution of stresses in screw with PICN crown and zirconia abutment in group S; **E**, Distribution of stresses in screw with PEEK crown and PEEK abutment in group C; **F**, Distribution of stresses in screw with PICN crown and PEEK abutment in group C; **G**, Distribution of stresses in screw with PEEK crown and zirconia abutment in group C; **H**, Distribution of stresses in screw with PICN crown and zirconia abutment in group C.

Table VI. The maximum stress of the screws in the two groups.

	Group S		Group C	
	PEEK abutment	**Zr abutment**	**PEEK abutment**	**Zr abutment**
PEEK crown	67.98	79.88	79.63	79.72
PICN crown	68.03	59.22	79.63	79.72

PICN, Polymer-infiltrated ceramic-network; PEEK, Polyetheretherketone; Zr, Zirconia.

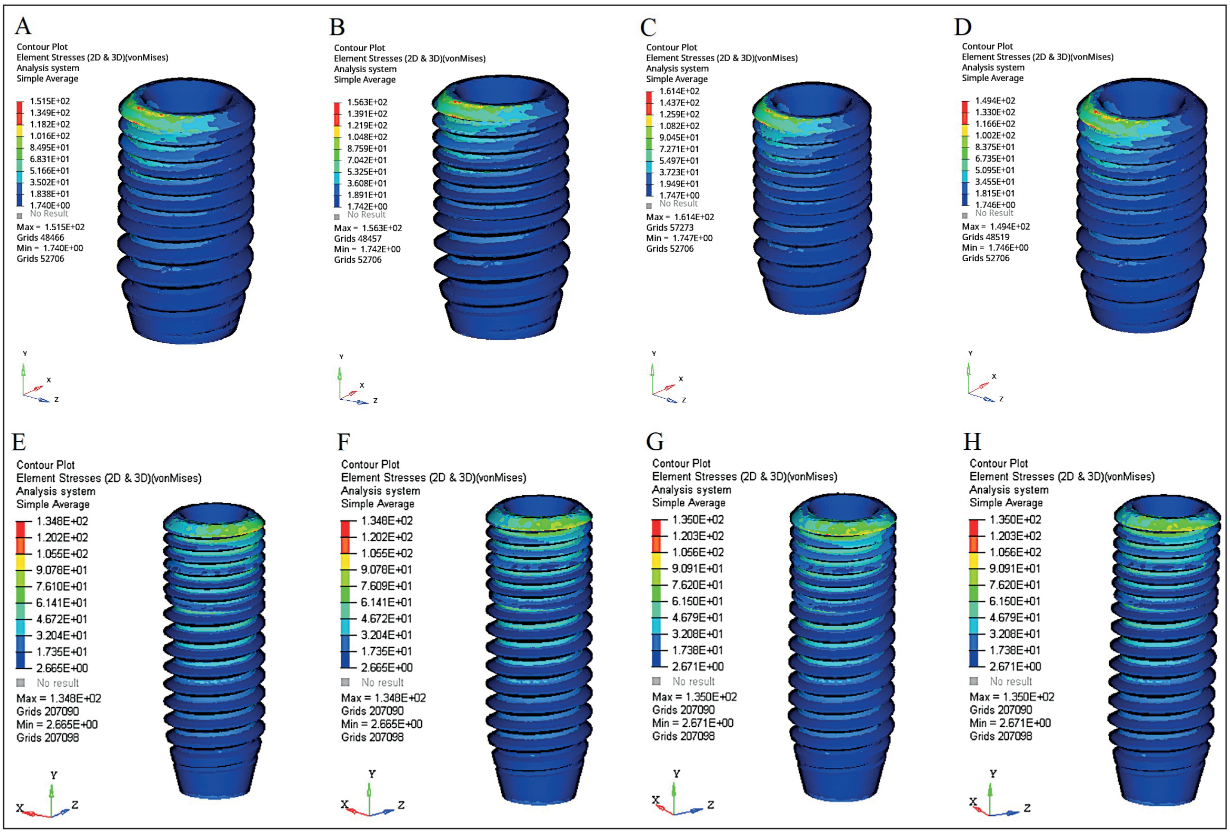

Figure 6. Distribution of stresses in implants in the two groups. **A**, Distribution of stresses in implant restorations with PEEK crown and PEEK abutment in group S; **B**, Distribution of stresses in implant restorations with PICN crown and PEEK abutment in group S; **C**, Distribution of stresses in implant restorations with PEEK crown and zirconia abutment in group S; **D**, Distribution of stresses in implant restorations with PICN crown and zirconia abutment in group S; **E**, Distribution of stresses in implant restorations with PEEK crown and PEEK abutment in group C; **F**, Distribution of stresses in implant restorations with PICN crown and PEEK abutment in group C; **G**, Distribution of stresses in implant restorations with PEEK crown and zirconia abutment in group C; **H**, Distribution of stresses in implant restorations with PICN crown and zirconia abutment in group C.

The stress distribution was different with PEEK crowns and PICN crowns. When the PEEK crowns were cemented on the PEEK abutments, the stress dispersed evenly. On the other hand, the stress was greatly concentrated on the axial angles when the PEEK crowns cemented on the Zr abutments. This may be because of the large disparities in the elastic modulus between PEEK and Zr[24]. The PEEK crown has large plastic deformation under loading, while the brittle Zr crown has little plastic deformation, thus leading to stress concentration.

The elastic modulus of PICN is larger than PEEK, therefore the stress dispersed more evenly when the PICN crowns were cemented on the Zr abutments, and the maximum stress value was lower. When the PICN crowns were cemented on the PEEK abutments, the stress distribution

Table VII. The maximum stress of the implants in the two groups.

	Group S		Group C	
	PEEK abutment	**Zr abutment**	**PEEK abutment**	**Zr abutment**
PEEK crown	151.50	161.40	134.80	135.00
PICN crown	156.30	149.40	134.80	135.00

PICN, Polymer-infiltrated ceramic-network; PEEK, Polyetheretherketone; Zr, Zirconia.

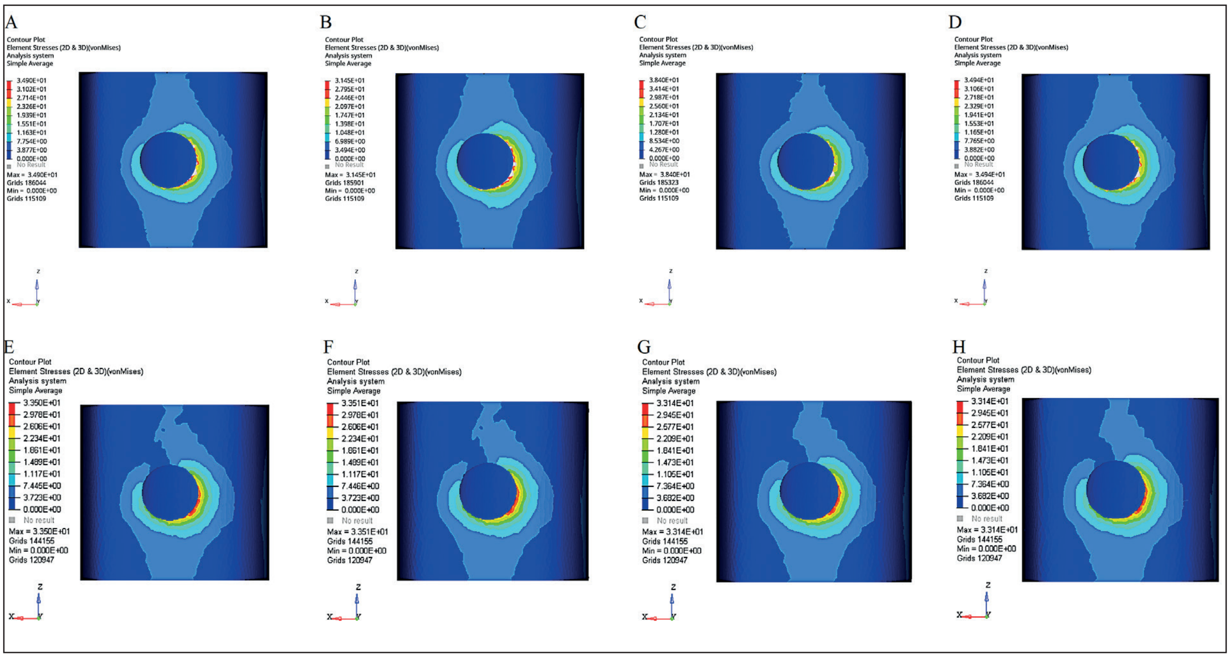

Figure 7. Distribution of stresses in peripheral cortical bones in the two groups. **A**, Distribution of stresses in cortical bones with PEEK crown and PEEK abutment in group S; **B**, Distribution of stresses in cortical bones with PICN crown and PEEK abutment in group S; **C**, Distribution of stresses in cortical bones with PEEK crown and zirconia abutment in group S; **D**, Distribution of stresses in cortical bones with PICN crown and zirconia abutment in group S; **E**, Distribution of stresses in cortical bones with PEEK crown and PEEK abutment in group C; **F**, Distribution of stresses in cortical bones with PICN crown and PEEK abutment in group C; **G**, Distribution of stresses in cortical bones with PEEK crown and zirconia abutment in group C; **H**, Distribution of stresses in cortical bones with PICN crown and zirconia abutment in group C.

region was significantly larger. This may because of the interaction effect of greater plastic deformations of PICN crowns and lower plastic deformations of PEEK crowns. Thus, the results of the present study indicated the combination of PEEK crown and PEEK abutment and PICN crown and Zr abutment are better as compared to combinations of PEEK crown and Zr abutment and PICN crown and PEEK abutment.

The stress distributions on the Ti-bases and prosthetic screws were greatly different between Zr abutment and PEEK abutment. When cemented with Zr abutment, the stress was concentrated on the connection part of Ti-base and middle part of screws, this may lead to a series of technical complications such as fracture of abutment screws and fracture of abutments. Although the maximum stress values were lower, the stress distribution patterns were more dangerous. The stress concentrated on the platform of Ti-base and head and middle-part of abutment screws when the crown was cemented with PEEK abutment, the maximum stress values were higher, but the risks of technique complications was lower.

The stress values in group S were lower than the group C. This may be because of the higher crown-to-implant ratio in group S, as the longer prosthesis dispersed more stress. The stress was lower when

Table VIII. The maximum stress of the cortical bones in the two groups.

	Group S		**Group C**	
	PEEK abutment	**Zr abutment**	**PEEK abutment**	**Zr abutment**
PEEK crown	34.90	38.40	33.50	33.14
PICN crown	31.45	34.94	33.51	33.14

PICN, Polymer-infiltrated ceramic-network; PEEK, Polyetheretherketone; Zr, Zirconia.

the crown cemented to PEEK abutment, this may indicate that the PEEK abutment is more suitable for the situation with high crown-to-implant ratio.

The overall stress distribution patterns were similar between the two groups and this may indicate that the marginal bone loss may be similar between the two implants. This is agreement with previous studies reporting outcomes of SDI[2,6,7].

Conclusions

Our study indicates that the PEEK material is more suitable for the hybrid restorations of SDI (6 mm). If the Zr abutment is used, the PICN crown would be better. Further, *in-vivo* clinical trials comparing these materials are needed to strengthen evidence.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' Contribution

TZH conceived and designed the study, JS, XZ collected data and performed data analysis. ZH wrote the draft of this manuscript. YG and HL edited the manuscript.

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