Original Article

In Vitro Evaluation of Marginal Adaptation of Polyether Ether Ketone and Zirconia Copings

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Abstract

Background: Polyether ether ketone (PEEK) has emerged as a new thermoplastic material with potential applications as a restorative material. **Aim:** This study aimed to evaluate the marginal adaptation of PEEK copings compared to zirconia copings using field emission scanning electron microscopy. **Materials and Methods:** A freshly extracted maxillary central incisor was prepared for a full-coverage restoration following standard principles of tooth preparation. The tooth was sent to a laboratory for fabrication of samples using computer-aided design and manufacturing (CAD/CAM). Twenty samples of polyether ether ketone (PEEK) copings (group A) and 20 of zirconia copings were fabricated (group B). The copings were scanned under a field emission scanning electron microscope and measurements were taken at four distinct points. The marginal adaptation over the buccal, lingual, mesial, and distal margins for both groups was evaluated. One-way analysis of variance (ANOVA) and independent *t* test were applied. **Results:** Our findings indicate that PEEK showed better marginal adaptation than zirconia at all measurement points. The mean marginal gap value of the PEEK group was 33.99 ± 8.81 µm and of the zirconia group was 56.21 ± 15.07 µm. On comparing marginal adaptation among the mesial, distal, buccal, and lingual aspects, PEEK showed better adaptation on all four margins, with the best adaptation on the buccal margin that had the lowest mean gap value of 29.27 ± 6.07 µm. The zirconia group adapted best at the distal margin, with a lowest mean gap value of 53.58 ± 15.25 µm ($P \leq 0.05$). **Conclusion:** PEEK copings had better marginal adaptation and fit compared to zirconia copings. It may have applications as a restorative material in fixed prostheses.

Keywords: *CAD/CAM, field emission scanning electron microscope, marginal adaptation, PEEK crowns, zirconia*

Received: 16-Oct-2022; **Revision:** 14-Dec-2022; **Accepted:** 04-Jan-2023; **Published:** 14-Jul-2023

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Access this article online

Quick Response Code:

Website: www.njcponline.com

DOI: 10.4103/njcp.njcp_701_22

How to cite this article: Chouksey P, Yadav NS, Hazari P, Saxena V, Mahajan H, Narwani S, *et al. In vitro* evaluation of marginal adaptation of polyether ether ketone and zirconia copings. Niger J Clin Pract 2023;26:701-8.

Introduction

Fixed partial dentures aesthetically replace missing teeth and improve masticatory efficiency, appearance, and phonetics.[1] There has been a rise in the number of people opting for esthetic crowns, which correlates with the rising number of partially dentate adults and increased life expectancy.[2] The quest for materials that mimic the appearance of natural dentition has led to innovations in esthetic restorative materials. Technological advancements have led to the use of computer-aided design and manufacturing (CAD/CAM) to provide reliable standard results with reduced operator error.[3] However, these fabrication methods are not infallible and are predicated on the material used.

The success of restoration is determined by its esthetics and fit. The fit of a restoration is determined by the presence of any gaps at internal and marginal interfaces. The marginal fit of the restoration influences the clinical performance and longevity of a restoration.[4] Microleakage remains an obstacle to clinical success and the main cause of the failure of a restoration. Microleakage at interfaces allows the penetration of substances, saliva, and accompanying bacteria into the gaps between the tooth and the restoration. Marginal gaps can result in caries, resolution of cement, defective margins, and periapical lesions.[5–7] *In vivo* studies have reported that marginal discrepancies of 7–65 µm are clinically acceptable, while other researches have deemed gaps of up to 100 µm acceptable.[8–10] In the case of CAD/CAM restorations, gaps of 50–100 µm are tolerable due to the inherent inaccuracy in different restorative materials.[11–13] A coping is a thin layer of material that covers the preparations to the margins. The thickness of the coping can influence the final shade of the crown.[14,15] Extremely thin copings can deform and cause sagging.[16] They need to be thin with a high elastic modulus to withstand occlusal forces. The demand for esthetic restorations has led to the rise of advanced tooth-colored ceramic copings. Ceramic restorations do not have a metallic component and thereby effectively avoid problems of corrosion, discoloration, and allergic reactions.[17,18] Ceramics show superior gingival response and esthetics while achieving marginal accuracies comparable to traditional metal-based restorations.[19,20]

Among all the CAD/CAM-processed materials, zirconia (ZrO_2 or zirconium dioxide) displays great potential owing to its excellent mechanical strength, low thermal conductivity, low corrosion potential, superior fracture resistance, and good esthetics.[21] The burgeoning popularity of zirconia crowns is due to the increased demand for metal-free restorations and their advantages in patient comfort. Zirconia crowns, when manufactured using the layering technique, have zirconia as the core which is porcelain veneered for adequate anatomic contour and esthetics. However, the layering technique makes these veneered ceramic crowns susceptible to fracture.[22] Additionally, long-term clinical studies have demonstrated that zirconia restorations display inadequate marginal adaptation, making them more prone to failure.[23] Newer materials continue to be evaluated for their predictability and long-term success.

Polyether ether ketone (PEEK) is a high-performance thermoplastic resin with favorable physicochemical properties. Chemically, it is a modified semi-crystalline polyarylether ketone that has seen a long history of use in orthopedics and dentistry.[24,25] PEEK displays superior biocompatibility, dimensional stability at high temperatures, high chemical and mechanical resistance against wear,[26] a Young's modulus similar to that of the human bone, and high flexural strength that makes it less susceptible to bulk fracture.[27,28] It has already found applications in implant dentistry and veneers.[29] Currently, polymers are increasingly being used for coping components. Few studies have closely examined PEEK, as it is a relatively new material to emerge for use in fixed prosthesis fabrication. Earlier comparisons have shown it to have excellent marginal and internal fit.[30] It shows structural integrity as a posterior tooth crown material, has survived more than a million chewing cycles with higher loads, and has few instances of catastrophic failure.[31] The novelty of this study is its evaluation of the marginal integrity of both PEEK and zirconia copings in relation to a natural tooth. Fabrication of coping done using CAD/CAM, and examination of marginal integrity using a field emission scanning electron microscope (FESEM), which is preferential for imaging polymer material in thin films.[32]

Studies examining the physicochemical properties of PEEK in fixed prostheses remain scarce. Hence the aim of this study was to conduct a comparative evaluation of the marginal fit of PEEK and zirconia copings using an FESEM in order to assess their clinical applicability in a fixed partial prosthesis.

Materials

This study received approval from the Institutional Ethics Board of People's Dental Academy, Bhopal, India (2019/IEC/300/2). This *in vitro* study was designed to inspect the marginal adaptation (fit) of PEEK and zirconia copings using addition polyvinyl siloxane impression material on freshly extracted maxillary central incisors and scanning them under FESEM.

Methods

The study comprised of 40 samples that were divided into two equal groups of 20 samples each (n = 20). Group A had 20 samples of PEEK copings and group B had 20 samples of zirconia copings that were fabricated using the addition polyvinyl siloxane impression material. This sample size was calculated using the OpenEpi sample size calculator based on the mean difference of two previously conducted studies.[22,33]

Specimen fabrication procedure

The inclusion criterion of this study was freshly extracted maxillary central incisors that were procured from the Department of Oral and Maxillofacial Surgery, People's Dental Academy, Bhopal from patients diagnosed with aggressive periodontitis who underwent extractions of mobile teeth. The extracted teeth were obtained only after informing and obtaining written and informed consent from the patient. Exclusion criteria included any teeth that showed evidence of caries, restoration, hypoplasia, trauma, developmental defects, or any other apparent defect.

Samples of groups A and B were fabricated using a common procedure. The selected extracted tooth was mounted on an acrylic resin block (DPI Cold Cure; Dental Products of India, Mumbai, India) with the cervical line of the tooth placed 1 mm superior to the top surface of the block. The tooth was prepared for a full-coverage, all-ceramic restoration following the standard principles of tooth preparation. Depth-orientation grooves of 1.4 mm on the labial and 2.0 mm deep on the incisal surface were given using a flat-end tapered diamond (TF 12- ISO 173/016). Three labial grooves were placed with the help of a diamond bur kept parallel to the gingival one-third of the labial surface. The second set of two grooves was made parallel to the incisal two-thirds of the uncut labial surface, giving it a two-planner reduction preparation. The remaining tooth structure between the depth-orientation grooves on the incisal portion of the labial surface was planed away. Lingual reduction with a depth orientation groove of 0.8 mm using a football-shaped diamond bur (No. ISO 257/018) was done. Bulk reduction was done using the round-ended tapered diamond bur which resulted in a heavy chamfer margin of 1 mm wide supra gingival, finishing was done creating rounded internal angles with and an overall taper of 6 degrees [Figure 1].[34]

Additionally, polyvinyl siloxane impression material (Aquasil soft putty- regular set; Dentsply DeTrey, Konstanz, Germany) was selected for making the impression of the prepared tooth following the manufacturer's directions [Figure 2].

The prepared tooth was scanned using a 3D dental scanner (Identica hybrid; MEDIT corp., Seoul, Korea). Forty coping cores were designed (Roland DWX-50, USA). Copings were divided into two groups.

Group A - 20 copings were made (K5; vhf camfacture AG, Germany) from PEEK blanks (breCAM.BioHPP Discs; Bredent, Senden, Germany).

Group B - 20 copings were made from zirconia blanks (Zenostar Zr Traslucent light, Pforzheim, Germany).

The criteria for both the groups were kept similar with the core thickness being set at 0.7 mm and the cement space set at 50 μm. The fit of the internal copings was checked by using a white silicone indicator paste (Fit-Checker, GC Dental, Tokyo, Japan) and an explorer. Interfering points between the inner surfaces of the copings and the prepared natural tooth was reduced at the coping using a bur; thus the standard criteria for all the copings were maintained.

Specimen test under field emission scanning electron microscope

All the four surfaces of each coping were scanned for marginal gap under a field emission scanning electron microscope (Zeiss Ultra Plus, Zeiss, Germany) [Graphs 1 and 2], a high-resolution microscope with excellent analytical performance. Values were recorded at 1000 × magnification and measurements were in micrometers, and the results were statistically analyzed. To stabilize the copings over abutment teeth during scanning, they were filled with a fit checker, seated on the natural tooth, and held in place for five minutes with maximum finger pressure to stimulate the clinical cementation procedure.

For measuring the marginal gap, the interspace between the most extended point of the intaglio surface of the copings and the margin of the prepared tooth was chosen at four points, that is, (A) at the buccal margin, (B) at the lingual margin, (C) at the mesial margin, and (D) at the distal margin [Figure 3]. Similarly, readings were obtained for both groups [Table 1] and [Table 2].

Statistical analysis

Data were entered in a Microsoft Excel spreadsheet (Microsoft Office, Microsoft Inc., Redwood, California, USA) and descriptive data were analyzed using IBM SPSS Statistics version 25.0 (IBM Corp., USA). One-way ANOVA and independent t test was applied to compare the mean scores. For all statistical purposes, $P \leq 0.05$ was deemed significant.

Results

Our findings indicated that the PEEK group showed less marginal gap compared to the zirconia group.

The average marginal gap value of the PEEK group was 33.99 ± 8.81 µm compared to the much higher 56.21 ± 15.07 µm for the zirconia group. The results showed a significant difference between the groups ($P = 0.000$) [Table 3].

For the buccal margin, marginal gap was greater in the zirconia group compared to the PEEK group. The mean marginal gap value at the buccal margin for the zirconia group was 57.45 ± 16.46 µm compared to 29.27 ± 6.07 µm for the PEEK group, and the difference between the groups was statistically significant ($P = 0.000$) [Table 4].

Similar to the results at the buccal margin, the PEEK group showed a reduced mean marginal gap value of

Table 1: Readings obtained for marginal fit in peek copings

Marginal fit in (µm)			
A Buccal	B Lingual	C Mesial	D Distal
23.8	24.4	33.5	33.3
24.2	41.6	37.0	42.4
24.4	30.6	40.8	39.2
29.8	30.3	44.4	51.2
23.9	28.4	34.3	49.6
33.0	47.9	51.0	50.4
51.0	47.9	50.4	33.9
24.9	6.49	33.5	34.4
31.6	43.2	50.1	48.6
25.4	24.1	37.1	39.6
24.7	34.4	40.1	47.2
28.4	31.2	31.3	33.6
28.9	29.2	29.6	40.4
31.6	22.5	45.1	30.2
26.4	27.8	30.1	38.3
32.6	26.8	21.3	33.2
29.7	30.4	30.9	31.4
27.2	23.1	34.2	39.1
32.3	35.6	22.4	29.8
31.7	37.7	26.4	41.3

Table 2: Readings obtained for marginal fit in zirconia copings

Marginal fit in (µm)			
A Buccal	B Lingual	C Mesial	D Distal
69.0	58.1	79.6	52.2
58.7	59.2	60.7	67.8
72.85	80.0	66.8	59.4
51.3	49.6	76.0	56.8
56.4	42.6	59.5	55.6
56.7	44.6	44.9	57.1
23.6	17.8	29.8	23.4
92.1	78.6	57.2	67.1
55.6	54.9	72.7	67.9
43.2	45.1	45.6	23.7
33.5	34.9	44.6	24.9
52.0	49.4	45.7	49.8
39.3	54.6	45.7	46.9
83.1	83.9	72.6	76.9
54.8	61.0	55.4	46.9
56.8	48.9	45.7	49.7
62.3	59.5	59.4	49.8
65.7	56.8	67.9	65.1
45.8	67.9	66.4	59.8
76.4	57.0	75.8	70.8

Figure 1: Prepared tooth for full-coverage, all-ceramic restoration

Figure 2: Impression with polyvinyl siloxane

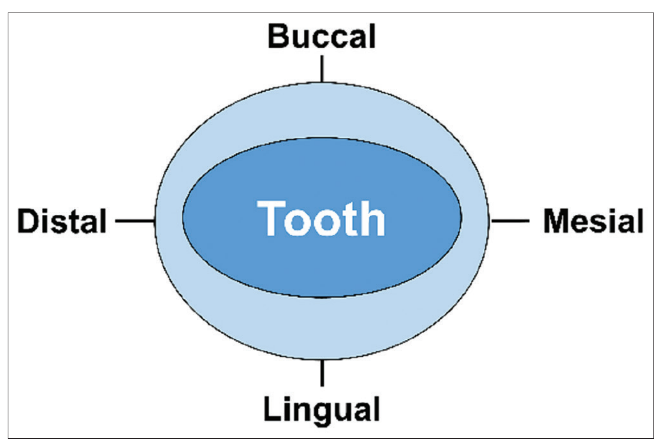
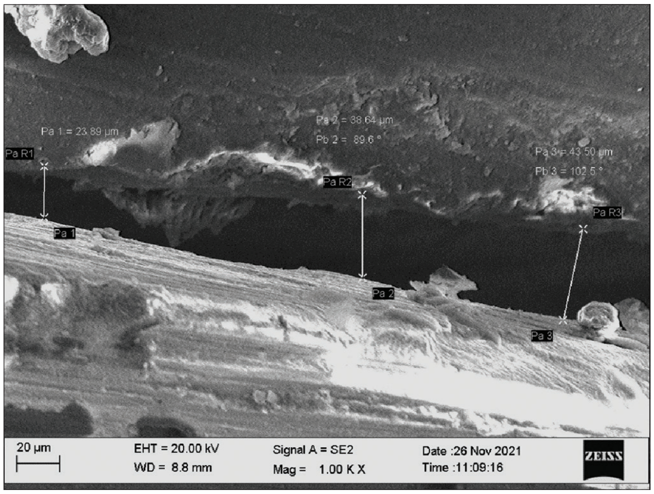
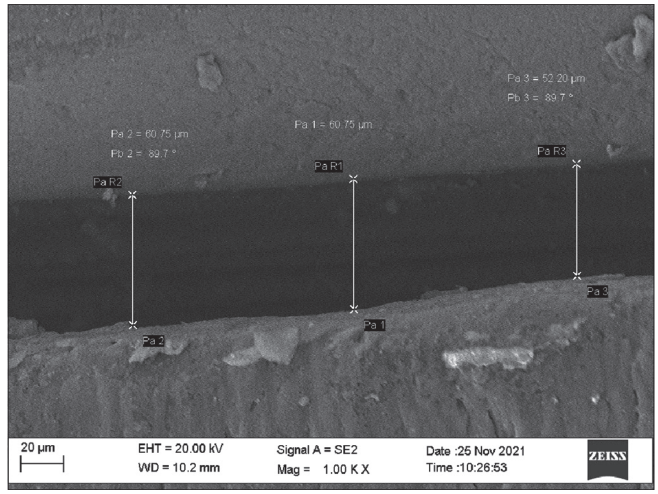


Figure 3: Sites of marginal fit evaluation



Graph 1: Field emission scanning electron microscope (FESEM) image exhibiting marginal gap in the buccal aspect of polyether ether ketone (PEEK) coping



Graph 2: Field emission scanning electron microscope (FESEM) image exhibiting marginal gap in the distal aspect of zirconia coping

Table 3: Comparison of marginal adaptation (fit) value of polyether ether ketone (PEEK) and zirconia groups

Groups	*n*	Marginal adaptation (fit) (µm) Mean±Standard Deviation	*P*
PEEK	20	33.99±8.81	0.000*
Zirconia	20	56.21±15.07	

Table 4: Comparison of marginal adaptation (fit) value of polyether ether ketone (PEEK) and zirconia groups according to margins

Margins	Groups	*n*	Marginal adaptation (fit) (µm) Mean±Standard Deviation	*P*
Buccal	PEEK	20	29.27±6.070	0.000*
	Zirconia	20	57.45±16.46	
Lingual	PEEK	20	31.17±9.665	0.000*
	Zirconia	20	55.22±15.42	
Mesial	PEEK	20	36.17±8.771	0.000*
	Zirconia	20	58.60±13.66	
Distal	PEEK	20	39.35±6.99	0.001*
	Zirconia	20	53.58±15.25	

31.17 ± 9.665 µm compared to 55.22 ± 15.42 µm in the zirconia group. And the difference between the group was significant (*P* = 0.000).

At the mesial margins, the mean marginal gaps were greater for the zirconia group compared to the PEEK group. The zirconia group showed a mean value of 58.60 ± 13.66 µm compared to 36.17 ± 8.771 µm in the PEEK group; the difference between the groups was significant (*P* = 0.000).

At the distal margins, the mean marginal gap was higher for the zirconia group compared to the PEEK group (39.35 ± 6.99 µm). For the zirconia group, the mean value was 53.58 ± 15.25 µm. Based on the results, it was observed that the difference between the mean marginal gap of the two groups was significant (*P* = 0.001).

Comparing the differences at each margin within the PEEK group, the buccal marginal gap showed the lowest mean (29.27 ± 6.07 µm) followed by the lingual margin (31.17 ± 9.665 µm) and the mesial margin (36.17 ± 8.771 µm). The distal margin showed the highest mean (39.35 ± 6.99), and the difference between the margins was significant (*P* =0.000).

When we compared the mean marginal gap value of all margins of the zirconia group, the distal margin showed the lowest mean (53.58 ± 15.25 µm) followed by the lingual margin (55.22 ± 15.42 µm) and buccal margin (57.45 ± 16.46 µm). The mesial margin showed the highest mean (58.60 ± 13.66 µm). The difference between the margins was insignificant (*P* = 0.728).

Discussion

Marginal accuracy is central to a restoration's structural durability and retention.

Improved control of marginal fit gives the restoration a natural appearance that is esthetically pleasing and functionally efficient. The use of an appropriate coping design allows for optimal thickness which can reduce stress and maximize long-term success. This study evaluated the marginal adaptation of PEEK copings compared to zirconia in natural human teeth using a field emission scanning electron microscope.

We found that there were significant differences in the gap measurements between the PEEK and zirconia groups at all measurement points. Overall, PEEK showed lower gaps and better marginal adaptation compared to zirconia. This finding was consistent with that of Amalorpavam *et al.*[35] who examined the marginal adaptation and internal adaptation of PEEK copings compared to zirconia on metal dies. They reported that PEEK copings showed better marginal fit and adaptation than zirconia. One salient difference between the earlier work and our study was that we used a freshly extracted maxillary central incisor, thereby allowing greater accuracy to simulate clinical conditions. Metal dies and acrylic samples are more prone to dimensional inaccuracy due to shrinkage and warpage.[36] Bae *et al.*[30] reported that mean marginal fit can vary with the tooth being examined.

We observed that PEEK consistently showed lower marginal gaps compared to zirconia at all measurement points, with an average of 33.99 ± 8.81 μm. This corroborates with an earlier work by Attia *et al.* who found that PEEK copings had a marginal gap of 45–78 μm depending on the fabrication procedure.[27] Literature reveals that a wide gap in copings is considered to be a clinically acceptable maginal gap. Von Fraunhofer and Mclean[37] declared that a marginal gap of 120–150 μm was clinically permissible. These values are higher than those in the study by Hung *et al.*[38] who reported that marginal gaps should be limited to 50–75 μm. Ucar *et al.*[39] suggested an even lower value of 62.6 μm for an acceptable marginal gap. These variations in the marginal gap values could be due to the different types of scanners, two-dimensional methods, scanning electron microscopes, and various milling machinery. The findings of our study for both PEEK and zirconia copings fit within the various values considered to be a clinically acceptable marginal discrepancy.

Overall, the average marginal gap value for zirconia copings was higher in comparison to PEEK copings at all measurement points. This may be attributed to a greater number of firing cycles for zirconia than that of PEEK. The findings of our research coincide with the study conducted by Bae *et al.*[30] who used three-dimensional analysis to evaluate the marginal fit of zirconia and PEEK copings. Our findings differ from the results of Meshreky *et al.*[40] who reported that vertical marginal gaps were greater in a sample of PEEK veneers compared to zirconia. Our outcome is contrary to that of Jayesh *et al.*[41] who reported that zirconia crowns showed better marginal fit compared to PEEK. Similarly, our findings do not align with those of Godil *et al.*[42] who reported that PEEK showed greater marginal gaps, which were clinically acceptable, compared to lithium disilicate. Chandrashekhar *et al.*[43] described the marginal adaptation of zirconia coping as being considerably superior on the buccal aspect. This differs from our finding in which zirconia showed the greatest adaptation at the distal aspect.

The varying results can be explained by differences in the fabrication techniques and the substrates chosen for examination.[27] We examined PEEK and Zircona copings over natural tooth while other researchers evaluated endocrowns asin the case of Jayesh *et al*.[41] and Godil *et al.*[42] where theyused a typhodont tooth. The dissenting results may also be an effect of the impression material/scanner used or overall inaccuracies in impression-making, CAD/CAM, and final sintering. The disparity in the zirconia group cannot be established without closely evaluating the entire CAD/CAM procedure employed by the individual researchers. Every step in the CAD/CAM processing network can account for the resulting error in manufacturing,[44] In our study, the PEEK and zirconia copings were fabricated using CAD/CAM technology to control the thickness and anatomy of the restorations during the fabrication process and to ensure enhanced fabrication speed, durability, and esthetics.[45] The impression material chosen was polyvinyl siloxane, which has excellent dimensional stability.[46]

Previous authors have used different methods for evaluating marginal discrepancy. Attia *et al.*[27] used a digital microscope with an integrated camera of magnification × 45. An *et al.* used a light microscope at × 50,[47] whereas Rajan[48] used a stereomicroscope at × 100 magnification. They provided limited results from widely separated measuring points; hence, calculated means usually demonstrate large standard deviations. Another reason may be the inability to differentiate between tooth structure and tooth-colored cement or the inability to identify the most apical part of the preparation margin. Margins of the crown and die may appear rounded when viewed under magnification and the findings are limited.[49] Scanning electron microscopes (SEMs) have also been used for examining marginal discrepancy.[50] SEM uses thermionic energy that has relatively low brightness, evaporation of cathode material, and thermal drift during operation. We used a FESEM, which is more advanced. FESEM does not heat the filament and produces a high-definition image with less electrostatic distortion and a spatial resolution <2 nm.[32]

Our findings indicated that copings made from PEEK and zirconia showed clinically acceptable marginal fit. Nevertheless, PEEK showed greater marginal adaptation at all points compared to zirconia. PEEK lends itself to processing within a digital workflow, making it an appealing choice in modern dentistry as an alternative material. PEEK also has some disadvantages: It has grey color which fails to achieve the esthetic effect of zirconia unless veneered with composite resin. The inert and hydrophobic surface of PEEK makes PEEK bonding with composite resin and abutment teeth difficult.

There are some limitations to this study. The procedure was performed under ideal conditions, which is different from being produced in an oral cavity. Different manufacturing techniques have a significant effect on margin precision. Pressed PEEK shows a greater marginal gap than CAD/CAM‑milled PEEK, both of which stayed within the clinical acceptance limit. As yet, only a few studies have examined the differences among various fabrication technologies, and further research is required for long‑term clinical studies on PEEK which is critical for the assessment of its lasting success and for establishing guidelines for its use.

Ultimately, the selection of material should not be based solely on marginal accuracy. The choice of material should be predicated on the existing clinical conditions and the patient's esthetic expectations.

Conclusions

Within the limitations of this *in vitro* study, the marginal fit of both PEEK and zirconia copings were acceptable for clinical application. PEEK copings showed greater marginal adaptability with a mean marginal gap value of 33.99 ± 8.81 µm compared to zirconia copings which showed higher discrepancy, with a mean marginal gap of 56.21 ± 15.07 µm. PEEK copings displayed the best adaptation on the buccal aspect, with the lowest mean gap value being 29.27 ± 6.07 µm. On the other hand, the zirconia group adapted best at the distal margin, with the lowest mean gap value being 53.58 ± 15.25 µm ($P \leq 0.05$).

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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