

Research Article

EVALUATION OF THE EFFECT OF CONNECTOR THICKNESS ON FRACTURE STRENGTH IN FRAMEWORK MANUFACTURED WITH POLY-ETHER-ETHER-KETONE (PEEK) AND POLY-ETHER- KETONE-KETONE (PEKK)

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ABSTRACT

Objective: Cobalt–chromium (Co-Cr) alloy, widely used as a standard material in implant-supported prostheses, was selected as the control group in this study. Polyetheretherketone (PEEK) and Polyetherketoneketone (PEKK) are high-performance polymers with favorable mechanical properties, proposed as alternatives to metals in posterior implant-supported prostheses. However, their fracture resistance in this indication remains unclear. This study aimed to evaluate and compare the fracture resistance of three-unit implant-supported frameworks made from Co-Cr, PEEK, and PEKK, with various connector cross-sectional dimensions.

Materials and Methods: A total of 126 titanium abutments were mounted onto implant analogs and embedded in acrylic blocks arranged in pairs to simulate premolar tooth loss. Frameworks with connector cross-sections of 6.25 mm², 12 mm², and 16 mm² were digitally designed and milled from Co-Cr, PEEK, or PEKK (n = 7 per subgroup), then cemented with zinc phosphate cement. Fracture resistance was tested using a universal testing device, and failure types were documented. Data were analyzed with the Kruskal–Wallis test, followed by Mann–Whitney U tests with Bonferroni correction.

Results: PEEK specimens showed plastic deformation and fracture, while PEKK and Co-Cr exhibited complete fracture. The 16 mm² connector groups had the highest fracture strength, followed by 12 mm² and 6.25 mm². Co-Cr recorded the highest mean values, followed by PEEK and PEKK. Differences between 12 mm² and 16 mm² in Co-Cr and PEKK were not significant. All groups exceeded physiological posterior occlusal forces.

Conclusion: Within the limitations of this in vitro study, PEEK and PEKK may be considered viable alternatives to Co-Cr for posterior three-unit implant-supported fixed dental prostheses.

Keywords: Dental Materials; Dental Prostheses; Co-Cr Alloy; Implant-Supported Dental Prosthesis; Polyetheretherketone; Polyetherketoneketone

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INTRODUCTION

Recent improvements in implant longevity and advances in dental materials have reshaped treatment approaches to edentulism. In contemporary practice, implant therapy is often regarded as the primary option, whereas removable prostheses and conventional fixed dental prostheses are increasingly considered alternative modalities.

In fixed prosthetic substructures, the connector cross-section is a key design variable governing stress concentration and fracture risk; therefore, this study compares the effect of varying connector dimensions on fracture strength.

Implant-supported posterior fixed dental prostheses are established options for partial edentulism, showing high survival but notable technical complications. Metal-supported substructures—particularly cobalt–chromium frameworks—remain conventional benchmarks for stiffness and mechanical reliability, and connector cross-sectional dimensions are key determinants of fracture resistance in three-unit fixed dental prostheses (FDPs) (1). With the increasing demand of patients for fixed and aesthetic prostheses, metal-free restorations have become popular in dentistry. Poly-aryl-ether-ketones (PAEK), which are high-performance polymers that were used frequently in orthopedics, have also been used in dentistry in recent years (2).

Polyetheretherketone (PEEK) is a high-performance, linear macromolecule belonging to the polyaryletherketone (PAEK) family (2). It possesses a semi-crystalline morphology, an aromatic backbone, and thermoplastic characteristics, making it suitable for demanding engineering and biomedical applications. The polymer is produced through the connection of ketone and ether functional groups between aromatic rings, and in its pure form, it exhibits a tan coloration (2).

PEEK and PEKK are high-performance, metal-free polymers with good biocompatibility and chemical stability. They have gained clinical use in dentistry and are considered alternatives in patients with metal sensitivity (3).

PEKK (polyetherketoneketone) is a relatively newer material compared with PEEK. As a semi-crystalline, readily processable thermoplastic engineering polymer, it ranks among the highest-performance members of the PAEK family. PEKK exhibits high thermal stability over a

broad temperature range, strong chemical resistance, and very good mechanical behavior (4).

PEEK and PEKK polymers in the PAEK family are used in dentistry in many fields such as temporary abutment, individual healing cap, temporary crown, three-unit fixed prosthetic prosthesis, framework material, occlusal splint, endo crown and root canal posts (5).

PEEK and PEKK materials have been used as framework material in FDPs and implant-supported fixed dental prostheses (ISFDP) in prosthodontics. It is difficult to establish the appropriate connector thickness in FDPs of short implant abutments. Therefore, it is important to determine the minimum acceptable connector surface area in PEEK and PEKK FDPs of short implant abutments. In fixed prosthetic substructures, connector design, including its thickness, plays a crucial role in minimizing fracture risk, while the choice of material also has a significant impact; thus, using sufficient connector dimensions in combination with high-performance polymers such as PEEK or PEKK provides more reliable outcomes (1). There are not enough studies in the literature on the use of PEEK and PEKK materials as framework material in prosthetic dental treatment.

This study aimed to evaluate and compare the fracture mechanics and fracture resistance of two-implant-supported, three-unit frameworks made from PEEK, PEKK, and cobalt–chromium (Co-Cr) with varying connector surface areas. The null hypothesis proposed that frameworks fabricated from Co-Cr, PEEK, and PEKK with varying connector cross-sectional areas would exhibit no statistically significant variation in fracture strength.

MATERIALS AND METHODS

An autopolymerizing acrylic (Imicrly, Türkiye) block measuring 2 cm × 2 cm × 4 cm was fabricated using a silicone mold. Two cylindrical holes, each 6 mm in diameter and spaced 7 mm apart, were prepared on the block with a hard bur. Standard implant abutments (Nucleoss, Türkiye) were secured to implant analogs using an implant wrench. The analogue–abutment assemblies were positioned into the holes filled with autopolymerizing acrylic, and their alignment was achieved with the aid of the parallellometer's analyzer rod. During the setting of the acrylic resin, the parallel positioning and 90° orientation to the base plane were repeatedly verified to ensure accuracy, resulting in the master model (Figure 1). For model standardization, a vinylpolysiloxane impression (Elite P&P, Zhermack



Figure 1. Working model

GmbH, Badia Polesine, Italy) of the master model was taken, and analogue–abutment pairs were inserted into the impression (Figure 1).

Subsequent working models were obtained by pouring autopolymerizing acrylic into these impressions, yielding a total of 63 models. Abutments were torqued to the analogs at 30 Ncm in accordance with the manufacturer's instructions. The master model was scanned using an inEos X5 scanner (Sirona, North Carolina, USA), and the data were transferred to Exocad Matera software for framework design. Cement space was standardized at 25 μ m, with a minimum framework thickness of 1.2 mm on occlusal surfaces and 0.7 mm on other walls (6). Connectors were designed in circular cross-sections with surface areas of 6.25 mm², 12 mm², and 16 mm² to maintain uniform geometry. The framework was modeled as a three-unit bridge with a semi-anatomical cusp, supported by the mandibular right first premolar and first molar abutments. This design was consistently applied to all frameworks.

Using direct laser metal sintering (DLMS), 21 metal frameworks (7 per connector size) were produced from Remanium cobalt–chromium alloy powder (Dentaurum, Ispringen, Germany) with a Concept Laser M2 device (Yamazaki Mazak, Oguchi, Japan) (Figure 2). Following the same digital design, 21 PEEK frameworks (7 per connector size) were milled from DD Peek MED blocks (Dental Direkt GmbH, Spenge, Germany) on a Roland DWX-51D five-axis milling unit (BLZ Dental, Wuhan, China) (Figure 2). Similarly, 21 PEKK frameworks (7 per connector size) were milled from Pekkton® ivory blocks (Cendres+Métaux, Biel/Bienne, Switzerland) using the same milling unit (Figure 2).

All framework specimens were cemented onto the abutments using zinc phosphate cement (Pentron, California, USA), applied by a single clinician in

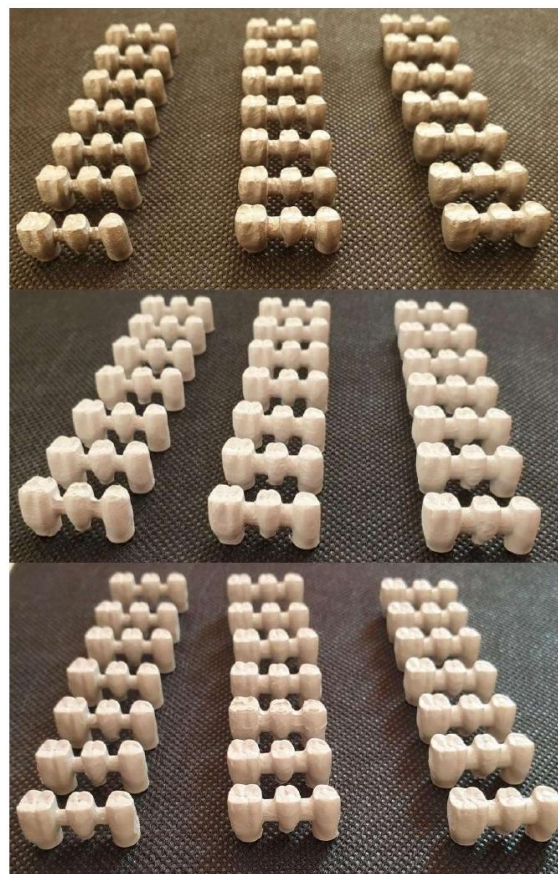


Figure 2. Co-Cr, PEEK and PEKK framework samples with connector surface areas of 6.25 mm², 12 mm², and 16 mm²

accordance with the manufacturer's guidelines, in order to reduce variability during cementation and to replicate clinical conditions. Following cementation, the samples were kept at 37 °C for a period of 24 hours prior to testing. Fracture resistance was assessed with Lloyd LRX Instron fracture testing machine (AMETEK, UK) (Figure 3) by delivering force through a 5 mm diameter steel ball positioned at the center of the pontic, oriented perpendicular to the framework's long axis, at a crosshead movement of 1 mm per minute. The load was applied until either irreversible plastic deformation or complete fracture took place (Figure3). The testing software recorded the applied forces in newtons (N), and the type of fracture was subsequently examined through macroscopic evaluation. Comprehensive information regarding the materials employed in this study can be found in Table 1.

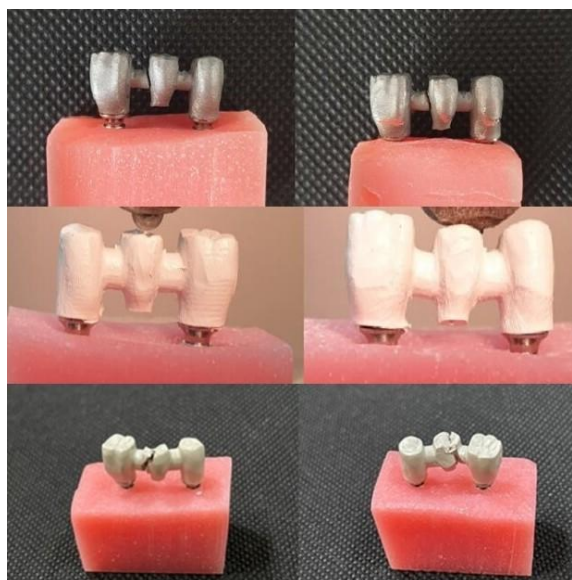


Figure 3. Specimens that fractured under the loads applied by the Lloyd LRX Instron fracture testing machine

Statistical analyses were performed at a 95% confidence level using SPSS 21 (IBM Corp., New York, USA). Power analysis indicated 99% power ($1 - \beta = 0.99$) for a 5% Type I error ($\alpha = 0.05$) with the sample size of 63. The Kruskal-Wallis test was applied to compare fracture strength across

Table 1. Information on the materials used in the study

Material	Product Name	Manufacturer	Composition
PEEK	DD Peek MED	Dental Direkt GmbH, Spenge, Germany	Polyether ether ketone, titanium dioxide
PEKK	Pekkton® ivory	Cendres Metaux, Biel/Bienne, Switzerland	Polyether ketone ketone, titanium dioxide
Co-Cr Alloy	Remanium	Dentaurum, Ispringen, Germany	60.5% Co, 28% Cr, 9% W, 1.5% Si
Cold Acrylic	Imicryl Cold Acrylic	Imicryl Dental, Konya, Turkey	PMMA methyl methacrylate diphenyl (2,4,6-Trimethylbenzoyl) phosphine oxide, activator, stabilizer
Zinc Phosphate Cement	Adhesor	Pentron, California, USA	Zinc oxide, magnesium oxide, phosphoric acid
Abutment	T6 standard abutment	Nucleoss, Izmir, Turkey	Grade V titanium
Analog	T6 standard stone analog	Nucleoss, Izmir, Turkey	Grade V titanium

materials and connector sizes, and pairwise comparisons were conducted with the Bonferroni-adjusted Mann-Whitney U test, with the correction factor calculated according to the number of comparisons.

RESULTS

For the frameworks with a connector cross-sectional area of 6.25 mm², the mean fracture strength values ($\pm$ standard deviation) were 2794.7 $\pm$ 379.9 N for cobalt-chromium (Co-Cr), 671.1 $\pm$ 95.5 N for PEEK, and 504.1 $\pm$ 56 N for PEKK (Table 2). Analysis with the Kruskal-Wallis test demonstrated statistically significant differences in mean fracture strength among these three materials ($p < 0.05$). Pairwise comparisons were performed using the Mann-Whitney U test with Bonferroni correction to determine which specific groups accounted for the observed differences. Considering that three materials were evaluated, the adjusted significance threshold was $0.05/3 = 0.0166$. The results indicated statistically significant differences for all pairwise comparisons ($p < 0.05$).

In the case of frameworks with a connector cross-sectional area of 12 mm², the mean $\pm$ standard deviation fracture strength values were 6868.2 $\pm$ 790.8 N for Co-Cr, 1151.5 $\pm$ 169.2 N for PEEK, and 504.1 $\pm$ 56 N for PEKK (Table 2). The Kruskal-Wallis analysis again showed statistically significant variation among the three groups ($p < 0.05$). Bonferroni-corrected Mann-Whitney U tests ($\alpha = 0.0166$) revealed significant differences between each pair of materials ($p < 0.05$).

For the frameworks designed with a connector cross-sectional area of 16 mm², the mean $\pm$ standard deviation fracture strength values were recorded as 2794.7 $\pm$ 379.9 N for Co-Cr, 671.1 $\pm$ 95.5 N for PEEK, and 764.7 $\pm$ 132.2 N for PEKK (Table 2). The Kruskal-Wallis test once more identified statistically significant differences among the three material groups ($p < 0.05$). Subsequent Bonferroni-adjusted Mann-Whitney U comparisons ($\alpha = 0.0166$) confirmed that all pairwise differences were statistically significant ($p < 0.05$).

PEEK frameworks exhibited both plastic deformation and complete fracture, whereas PEKK and Co-Cr frameworks exhibited complete fracture only. Among the 21 PEEK frameworks, 13 showed permanent deformation and 8 showed complete fracture. PEKK frameworks fractured completely shortly after load application.

An increase in connector surface area from 6.25 mm² to 12 mm² resulted in a statistically significant increase in

Table 2. Descriptive statistical evaluation of fracture resistance values for 6.25, 12 and 16 mm² groups with statistical tests

	6.25 mm ²	12 mm ²	16 mm ²
Co-Cr	2371	6912	7994
	2492	8314	4973
	2686	5667	7185
	2672	6753	7706
	2958	6453	7896
	3528	7023	7632
	2856	6956	7896
	576	1385	1348
	613	1083	1658
PEEK	738	1376	1439
	639	1095	1565
	565	1107	1378
	771	919	1428
	796	1096	1582
	451	650	691
	497	865	1030
	484	861	1002
	576	861	1016
PEKK	443	800	1204
	493	518	844
	585	798	1184

All pairwise comparisons among Co-Cr, PEEK, and PEKK were statistically significant ($p < 0.05$).

fracture strength for all three materials. Increasing the connector surface area from 12 mm² to 16 mm² significantly increased the fracture strength in PEEK frameworks only. However, this increase was not statistically significant for Co-Cr and PEKK frameworks.

DISCUSSION

In light of the results of this study, the null hypothesis could not be upheld, as the analysis revealed statistically significant variations in fracture strength among the Co-Cr, PEEK, and PEKK frameworks. Cross sectional connector surface area had a significant effect on the fracture strength of two implant supported 3-unit frameworks.

Connectors link the pontic and the abutments, transferring occlusal loads between them. Because they are relatively thinner than the pontic and abutment, connectors become the most vulnerable regions of the framework under occlusal stress. Finite element analyses have shown that the highest stress concentrations occur at the gingival aspect of the connector area, emphasizing the importance of appropriate connector dimensions in preventing fractures (12). In this study, increasing the connector cross-section significantly enhanced fracture strength, supporting the principle that sufficient connector size, combined with suitable framework material, contributes to the long-term success of implant-supported prostheses. In a finite element analysis study by Alberto et al., increasing the connector height from 3 to 4 mm (and 5 mm) resulted in a notably lower and more uniform stress distribution (7).

In cases where posterior partial edentulous condition is treated with implant-supported fixed prostheses (ISFP), metal-ceramics, full ceramics, zirconia and polymers can be preferred as prosthetic material. Metal-ceramic restorations are considered the 'gold standard' among all ceramic restorations (8). A 2014 review by Daou supports that, for metal-ceramic fixed partial dentures (FPDs), a minimum connector occlusogingival height of 2.5 mm and buccolingual width of 2.5 mm—equating to a cross-sectional area of 6.25 mm²—are sufficient to ensure long-term success, applicable to both anterior and posterior restorations (9).

In this study, the minimum connector surface areas recommended for metal ceramics, zirconium oxide and full ceramics, which are frequently used in posterior implant supported restorations, were preferred and it was investigated whether PEEK and PEKK materials could be clinically successful at these connector sizes. According to the data obtained in this study, Co-Cr, PEEK and PEKK frameworks with 6.25 mm² connector surface area showed mean fracture strength value of 2794 N, 671 N and 504 N, respectively.

For the two-implant-supported, three-unit Co-Cr, PEEK, and PEKK frameworks with a 6.25 mm² connector surface area, the differences in mean fracture strength values were statistically significant.

All these mean values are above the recommended minimum fracture strength value of 500 N in the posterior region and can be concluded as being appropriate for clinical use. However, 504 N, the mean fracture strength value of PEKK frameworks with the connector surface

area of 6.25 mm² is very close to the critical fracture strength value recommended for the posterior region. Physiological biting forces in the posterior region are affected by factors such as age, gender, weight, presence of parafunctional habits, differences in proprioception. Therefore, in situations where PEKK frameworks incorporating connectors with a cross-sectional dimension of 6.25 mm² are planned, it is essential to obtain a detailed patient history and perform an accurate evaluation of the individual's bite forces.

According to the data obtained in this study, Co-Cr, PEEK and PEKK frameworks with 12 mm² connector surface area showed mean fracture strength value of 6868 N, 1151 N and 764 N, respectively. All these mean values are above the recommended minimum fracture strength value of 500 N in the posterior region and can be concluded as being appropriate for clinical use.

For the two-implant-supported, three-unit frameworks with a 12 mm² connector surface area, the mean fracture strength values of Co-Cr, PEEK, and PEKK showed a statistically significant difference.

According to the data obtained in this study, the difference between the fracture strength values of Co-Cr, PEEK and PEKK frameworks by increasing the connector cross-sectional areas from 6.25 mm² to 12 mm² was found to be statistically significant.

According to the data obtained in this study, Co-Cr, PEEK and PEKK frameworks with 16 mm² connector surface area showed mean fracture strength value of 7326 N, 1485 N and 995 N, respectively. All these mean values are above the recommended minimum fracture strength value of 500 N in the posterior region and can be concluded as being appropriate for clinical use.

A statistically significant difference was observed in the mean fracture strength values among the two-implant-supported, three-unit Co-Cr, PEEK, and PEKK frameworks with a connector surface area of 16 mm².

An increase in the connector cross-sectional area from 12 mm² to 16 mm² did not result in a statistically significant difference in the fracture strength values of the Co-Cr and PEKK frameworks. The frameworks fabricated at both connector cross-sectional area values are strong enough to withstand the posterior occlusal forces and are appropriate for clinical use. In cases where there is limited interocclusal space in the posterior region, when it is not possible to increase the connector cross-sectional area, Co-

Cr and PEKK frameworks with 12mm² connector surface area can be preferred.

However, the difference between the fracture strength values of PEEK frameworks by increasing the connector cross-sectional areas from 12 mm² to 16 mm² was found to be statistically significant.

A prior investigation assessing the fracture resistance of non-veneered, three-unit PEEK frameworks fabricated through CAD/CAM technology found that a connector cross-sectional dimension of 7.36 mm² resulted in an average fracture load of 1383 N (10). In comparison, the present study determined that two-implant-supported, three-unit PEEK frameworks with a smaller connector area of 6.25 mm² exhibited a mean fracture strength of 671 N.

Over time, such restorations may be susceptible to both biological and technical complications. A framework fracture rate of 13% was reported in studies evaluating implant survival and prosthetic complications in mandibular implant-supported, metal-acrylic resin complete dentures. (11). This study has certain limitations, veneering materials were not included in specimens, which may have affected the fracture resistance. Moreover, thermal cycling and long-term fatigue loading were not performed, thereby limiting the extrapolation of the results to intraoral conditions. Zinc phosphate cement was selected due to its long history of clinical use, dimensional stability, and ease of application in in-vitro settings (12). Although zinc phosphate cement exhibits a slight setting expansion, this property was considered negligible in the context of our experimental design and has been reported in the literature not to significantly influence the fit of fixed dental prostheses.(13)

In another study investigating the complication rates in implant-supported prostheses, reported the framework fracture as 0.6% in a 6-year follow-up (14).

In the literature, the most common causes of framework fracture are improper alloy usage, reduced cross-sectional connector surface area towards the distal of the most posterior implant. Particular attention should be given to the choice of alloy type, framework design and connector thickness (15). Although fracture of the framework material is not a common technical complication, it is important because it requires replacement of the entire prosthesis. The fracture resistance of a FDP should be high enough to withstand the patient's maximum bite force, which may vary depending on the patient's age, gender,

parafunctional habits, presence of implants, number of teeth, and similar factors (16).

Posterior biting forces are three times higher than anterior forces (17). Biting forces anticipated in a patient can present challenges during oral rehabilitation planning. Assessing the maximum bite force parameter plays a significant role in determining implant selection, as well as in the design of the prosthesis and occlusion.

In a clinical investigation involving 40 individuals with natural teeth in the opposing arch, the bite force for a three-unit fixed dental prosthesis supported by two posterior implants on one side was reported to range between 409 N and 804 N. In the same clinical study, the bite forces in the posterior region of the natural teeth were found to be in the range of 490-800 N (18).

Researchers attributed this wide range in bite force to individual differences and differences in test methods. The interocclusal distance, the tooth area where the bite force is measured, the position of the head during the measurement affects this value. Individual factors affecting bite force include age, gender, craniofacial morphology, height and weight (19).

In fixed partial dentures in the posterior region, the fracture resistance should be at least 500 N (20).

Fracture strength plays a critical role in the long-term clinical performance of implant-supported prostheses, particularly in situations where the available interocclusal space is limited. The restoration's geometry, the intricate biomechanics of mastication, the characteristics of human occlusion, and the complex structure and mechanical behavior of teeth and their supporting tissues, as well as the type and consistency of food, cannot be fully replicated with complete accuracy even in the most advanced chewing simulators (21). Consequently, laboratory-based evaluations can offer only a partial prediction of the actual in vivo behavior of the tested restorations.

CONCLUSION

Within the limitations of the present in vitro study, an increase in connector cross-sectional area resulted in improved fracture resistance of the frameworks, regardless of the material used. Fracture strength values differed significantly among frameworks manufactured from Co-Cr, PEEK, and PEKK. PEKK frameworks demonstrated markedly lower fracture resistance compared with those produced from PEEK. However, for

two-implant-supported, three-unit frameworks fabricated from Co-Cr, PEEK, and PEKK with connector sizes of 6.25 mm², 12 mm², and 16 mm², the mean fracture strength values exceeded the physiological occlusal forces typically encountered in the posterior region.

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Not applicable.

Authorship contributions

Concept/Design – MZ, F.B; Data Collection – F.B, M.Z; Analysis/Interpretation – BE, MZ; Literature Review – BE, MAA; Manuscript Preparation – BE, MAA; Critical Review – BE, MAA.

Data availability statement

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

Declaration of competing interest

The authors declare that they have no conflicts of interest.

Ethics

This in vitro study was approved by the Clinical Research Ethics Committee of Hatay Mustafa Kemal University, Faculty of Dentistry (Approval No: 2020/27).

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