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Original Article

The effect of aging on the accuracy of marginal adaptation and fracture resistance of CAD/CAM PEEK single crown restoration

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Aim: In recent years, great advances have been made in the use of CAD/CAM to prepare fixed restorations. The marginal and internal fit of these restorations is a principal determinant for their clinical success. In addition, the nature of the oral environment affects the mechanical properties of these restorations. Therefore, this study aimed to investigate the effect of aging process under conditions that simulate the oral environment on the marginal adaptation, and, fracture resistance of crowns fabricated from polyether ether ketone (PEEK) using CAD/CAM methods. **Methods:** Twenty identical crown restorations were fabricated by using CAD/CAM methods to mill polyether ether ketone (PEEK) material. These crowns were produced by using a software design of an epoxy resin replica of the prepared maxillary first premolar tooth. All PEEK crowns were cemented and randomly divided into two equal groups (A, B). Each group was divided into subgroups (A1, A2 and B1, B2). Group A1 and A2 were used to measure marginal adaptation and fracture resistance, respectively, before aging, while group (B1 and B2) were measured after aging. The cemented crowns were mounted in resin molds to facilitate the sectioning process. The measurements of the marginal gap were performed after sectioning at four points using a stereomicroscope. The fracture resistance of the crowns was investigated using a universal testing machine. A statistical analysis was performed using the GraphPad Prism® software version and unpaired Student's t-test. **Results:** The results revealed that aging affected the marginal gap, and the fracture resistance of the PEEK crowns. While aging, negatively affected the conditions under investigation, however the least significant difference of marginal gap was found in the margin region. **Conclusions:** PEEK-CAD/CAM is considered as a good alternative prosthodontic material for fixed prostheses. The CAD/CAM technique used to make PEEK crown restorations in our study offers the advantages of high marginal accuracy and fracture resistance for long-term performance in the oral environment.

Keywords: Computer-Aided Design. Ketones. Polymers. Dental marginal adaptation.

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Introduction

Marginal and internal adaptation of fixed prostheses are one of the significant factors that affects prosthodontic treatment success. The marginal fit preserves healthy periodontal tissues, prevents cement dissolution and increases retention of the prostheses. Many clinical problems can arise from inaccurate fabrication of dental prostheses, such as, recurrent carries, deposition of dental calculus, plaque accumulation and restoration failure[1,2].

The selection of the best treatment modality for patients has been greatly influenced by the recent advances in material science and technologies[3]. At present, prosthodontic materials, can be accurately produced by new technologies that include computer-aided design (CAD) and computer-aided manufacturing (CAM) techniques to exactly produce the intended design of the prostheses. These methods can produce prostheses with excellent quality in less time than the conventional techniques[4].

Therefore, demands for dental restorations have increased the need for these aesthetically improved and biocompatible materials[4-6].

Polyether ether ketone (PEEK) is a popular prosthodontic material. It is a strong material that is suitable for tooth color matching, and it has been widely used as a metal-free fixed partial denture framework[4,7-9]. PEEK is a rigid, light in weight and more aesthetically pleasing than other materials; therefore, it causes less torque on the abutment tooth. Due to the fact that PEEK has the ability to resist fracture forces and to dissipate these forces that cause fracture, this material has shown good clinical performance, and it can be considered as a good substitute for glass and metal ceramics. The value of Young's modulus and the tensile properties of PEEK are close to those of human bone, enamel and dentin[10]. In addition, it possesses high biocompatibility, good mechanical properties, high stability when exposed to thermal and chemical changes, ability to be polished, good wear resistance, low plaque affinity and high bond strength with composite veneers and luting cements[10].

Marginal fit that provides the seal and the uniform internal gap are two important criteria to consider in establishing the precise fit of restorations[11]. To enhance the retention and resistance quality of restorations, a uniform internal gap is recommended to provide the proper space for luting cement[4,12-14].

It has been reported that the presence of marginal microleakage at the tooth-restoration interface of resin cement has negatively affected the fracture resistance of full-ceramic fixed prostheses[15-17]. Multiple studies have measured the accuracy of marginal and internal fit of fixed prostheses. However, it is almost impossible to make a comparison because different findings were obtained under different testing conditions. Therefore, several studies have been conducted to establish relationships between these two properties and restoration prognosis[1,18-21].

Since this matter is very important, the aim of our study was to evaluate the effects of aging on the accuracy of marginal adaptation and fracture resistance of pre-polymerized PEEK single crowns prepared by CAD/CAM technique using a standard cross-sectional method. Although the methodology was not following the current standard, it was selected on the basis of results published in 2019[22].

Materials and Methods

A total of twenty PEEK full crown restorations of a maxillary first premolar phantom typodont tooth (Nissin, Dental Product) were prepared by CAD/CAM and used to study marginal adaptation and fracture resistance.

Restoration fabrication (Figure 1)

The maxillary first premolar phantom tooth typodont was scanned before preparation with a dental laboratory optical 3D scanner Vinyl (Smart optics sensortechnik GmbH Lise-Meitner, Germany), and the data were saved in a standard tessellation language (STL) file. This phantom tooth was prepared for a full crown with the following specifications: 1.5 occlusal reduction, 6 degree vertical angle; the convergence angle of the wall was prepared to approximately 60° and 1mm chamfer margin using a high-speed hand piece with water cooling.

The prepared phantom tooth was rescanned with the dental laboratory scanner using an optical 3D scanner, and software was used to obtain a prepared die tooth. After the scanning step of the workflow, the design of the crown was undertaken in the CAD software package (Exocad GmbH, Darmstadt, Germany). The smart software automatically defined an ideal path of insertion, detected the marginal line, and a cement gap (38μm) was selected. The scan data were exported for use in CAD software. The thickness of the crown was set according to the data that were previously saved before the preparation.

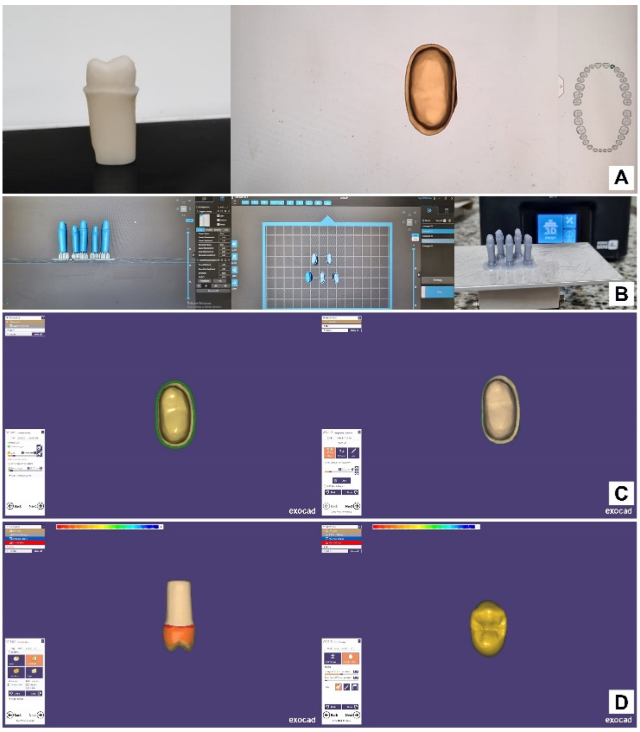


Figure 1. Crown design process using CAD/CAM software (Exocad): a-Prepared tooth specimens and the tooth scan, b-prepared epoxy resin replica, c-design of the cement gap and path of insertion, d-selected crown design.

The scanned die tooth was duplicated by using a 3D printer (Phrozen Sonic Mini 4K 3D printer, USA), suitable for printing using epoxy resins (Mammoth resin for model hard tough resin, China), to prepare twenty identical epoxy resin dies.

The crown restorations were designed by CAM software were milled from pre-polymerized blocks of PEEK (Bredent, Brecam BioHPP, GmbH, & Co, KG Germany) using a milling machine. All crown restorations were examined for any defects and cracks, and the internal surfaces were cleaned with distilled water.

Twenty identical crown restorations were cemented on their respective epoxy resin dies with a resin luting cement Panavia F (Kurary, Dental Inc, Japan) according to the manufacturer's instructions at a static load of 10 N for 10 min using a specially designed loading device. Excess cement was removed after initial setting using a scalpel, and the margin interface was smoothed with flexible disks.

All the cemented crowns were stored in distilled water at room temperature (37ºC) for 24 hours until the marginal adaptation and fracture resistance were measured before and after aging.

Then, the twenty cemented crown restorations were divided into two groups (Group A and Group B) of ten. Groups (A) and (B) were subdivided into (A1, A2) and (B1, B2) each with five restorations, as shown in Table 1:

Table 1. Grouping

Groups	Subgroup A1	Subgroup A2
Group (A)	Five cemented crown restorations used for measuring marginal adaptation before aging	Five cemented crown restorations used for measuring fracture resistance before aging
Group (B)	**Subgroup B1**	**Subgroup B2**
	Five cemented crown restorations used for measuring marginal adaptation after aging	Five cemented crown restorations used for measuring fracture resistance after aging

Measurements of marginal gap (adaptation)

The marginal gaps of the crown restorations of subgroup (A1) were measured before aging and subgroup (B1) after aging by sectioning the crown of the tooth at the central fossa to evaluate four points at mesiobuccal (MB), distobuccal (DB), mesiopalatal (MP) and distopalatal (DP). The measurements (in mm) were made at the occlusal region, line angle, mid-axial wall and margin area using a stereomicroscope (Olympus Zoom Stereo Microscope, Japan, Model NO. 521145 TRPT) at X20 magnification.

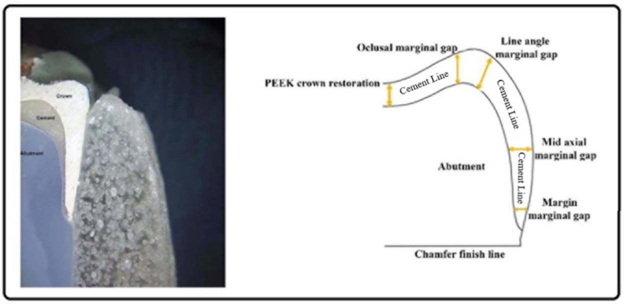


Figure 2. Schematic illustration of measuring the marginal gap of subgroup A1 and subgroup B1 after sectioning the cemented crown at four points (occlusal, line angle, mid-axial and margin)

Aging of the cemented crowns restoration

The remaining cemented crown restorations (subgroup B1 and subgroup B2) were artificially aged by thermal cycles and load cycling. They were subjected to 600 thermal cycles and 120000 mechanical load cycles up to 50 N in a water bath (5 to 55 °C) with a dwell tie (immersion time) for 30 seconds before testing[23-25].

Measurement of fractur.e resistance

The cemented crown restorations of subgroups (A2) before artificial aging and subgroups (B2) after artificial aging were subjected to compression loads in a universal testing machine (Zwick/Roell 1445; Zwick, Ulm, Germany) at a cross-head speed of 1 mm/min with a steel ball (diameter 5 mm) placed on the center of the occlusal surface between the buccal and palatal cusps until fracture occurred; and fracture loads (N) were recorded (Figure 3). To achieve an even force distribution, a 0.5 mm thick piece of tin foil (Dentaurum, Ispringen, Germany) was placed between the occlusal surface and the loading ball.

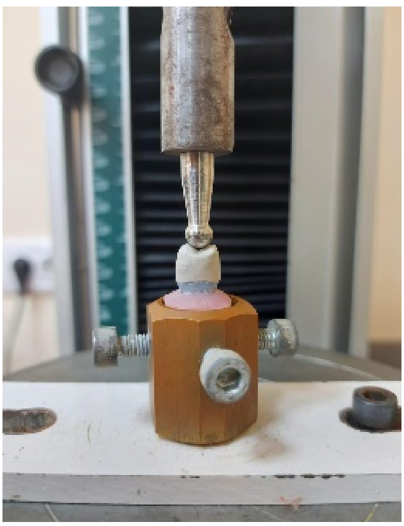


Figure 3. A PEEK crown restoration subjected to cyclic loading.

Statistical Analysis

The results for parametric data were expressed as the mean ± SD. Comparisons between the two groups (before and after aging) were analyzed using the Student's t-test. A statistical analysis was performed using the GraphPad Prism® software version 9.4.1 (681) (CA, USA). The significance of the obtained results was determined at the 5% level. Post hoc computation for achieved power was calculated using G*Power version 3.1.9.2 to determine the sample size.

Results

The mean value and the standard deviation of the marginal gap for subgroup (A1) before aging and subgroup (B1) after aging are graphically shown in Figure 4.

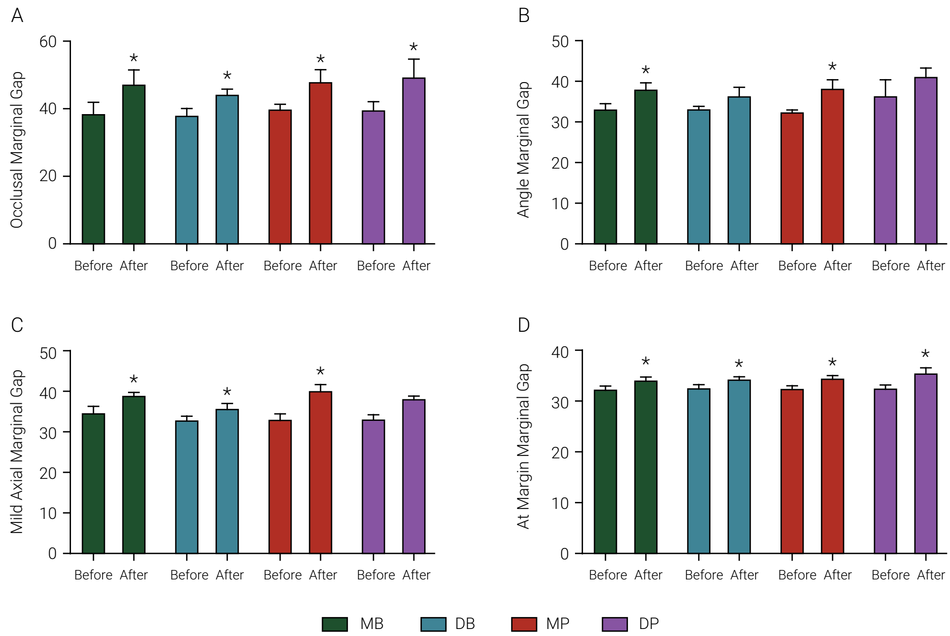


Figure 4. The marginal gap before aging (subgroup A1) and after aging (subgroup B1). A: Occlusal marginal gap, B: Angle marginal gap, C: Mid-axial marginal gap and D: Margin marginal gap.

After aging, there were statistically significant differences in the marginal gaps of cemented crown restorations at the occlusal region among the four-measurement points MB (P=0.041), DB (P=0.003), MP (P=0.006) and DP (P=0.019). The occlusal region showed a higher mean value in subgroup (B1) after aging.

Additionally, there were statistically significant differences in the marginal gaps of the cemented crown restorations at the angle region after aging among the MB (P=0.002), and MP (P=0.002), but at the DB (P=0.058) and DP (P=0.064), there were no statistically significant differences.

In the mid-axial region, there were statistically significant differences in the marginal gaps of cemented crown restorations after aging among the MB(P=0.004), DB (P=0.011), and MP (P<0.001), however, at the DP (P=0.097), there was no statistically significant difference.

Finally, in the margin region, there were statistically significant differences in the marginal gaps of cemented crown restorations among the MB (P=0.003), DB (P=0.005), MP (P=0.001) and DP(P=0.003). The lower mean value was shown in subgroup (A1) before aging.

The mean value and standard deviation of fracture resistance are shown in Figure 5, and Graph 1. The mean value of fracture resistance of subgroup (A2) before aging was 1162.16 ± 2.88 N while subgroup (B2) after aging was 732.34 ± 29.59 N. A comparison between subgroup (A2) and subgroup (B2) revealed a statistically significant difference (P ≤ 0.05). Subgroup A2 showed a higher mean value.

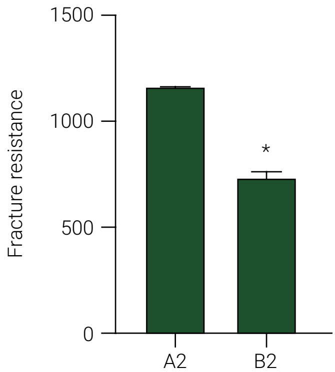
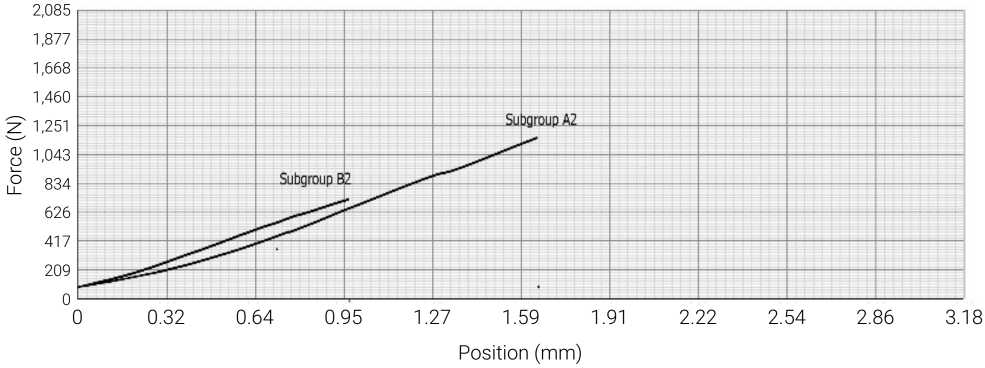


Figure 5. The fracture resistance of the tested subgroup (A2) before aging and subgroup (B2) after aging.



Graph 1. Load displacement curve for CAD/CAM PEEK crown restoration in subgroup A2 and subgroup B2.

Discussion

A definitive restoration is considered successful when it exhibits a good marginal fit that is strong enough to withstand the oral environment.

PEEK was used in our study for the fabrication of crown restorations due to its excellent mechanical, physical and chemical properties. It proved to be a suitable material for fixed dental prostheses (FDPs) and long-term restorations because the material was milled from a pre-polymerized block that did not undergo polymerization shrinkage during processing and decreased the risk of porosities[8,26-29].

The PEEK crowns were fabricated with CAD/CAM techniques. The crown restorations were designed by using CAD software, which in turn sent commands to the CAM unit for fabrication of the restoration[10].

Our study was conducted using software that scanned the maxillary first premolar before preparation, and these data were saved. The same tooth was prepared and rescanned to exactly reproduce twenty identical resin dies to minimize any errors reproduced from the nonstandard protocol used to assess the marginal gap of dental restoration, which might lead to false interpretation and limit their comparison with the results of other studies[1].

The crown restorations were cemented to their respective epoxy resin dies with resin cement. This technique was selected because it was simple and able to bend to tissues without any previous treatment, such as etching, priming, or bonding, and the cement has a high viscosity[10]. The crown restorations were stored in a 37°C water bath for 24 hrs before testing to represent the exact oral temperature, which may increase the polymerization of resin cement[30].

In this study, measurements of the marginal gap (32-46 μm) were acceptable. This result was in accordance with the Mclean study (≤ 120), as the PEEK crowns demonstrated superior marginal gaps that were more uniform than required and within the clinical acceptable range[2,31].

The method used in this study for sectioning cemented PEEK crown restorations provided good accuracy and could be easily visualized with a stereomicroscope for imaging quality and good distinction between the different materials[5].

The mean marginal gap was larger after aging at the occlusal, line angle, mid axial and margin areas than before aging. The aging process used in this study exactly represented the conditions of oral environments and simulated clinical situations for fitting the crown restorations[32]. However, the increase in marginal gap after aging, can also, be explained by the fact that the marginal gap in milled restorations is related to the brittleness index (BI), which is the ratio of the hardness and the fracture toughness of the material. A larger brittleness index is obtained by increasing of the hardness value and decreasing the fracture toughness value. As a result, this can affect the chipping factor (CF), which is the ratio of total margin chipping over the total marginal circumference of the restoration multiplied by 100 (%)[33]. Thus, this may induce microfractures formation at the restoration margins, which increases the marginal gap.

In addition, the larger mean value was found at the occlusal region may have been be due to thermal and load cycling, which induced degradation of the cement adhesive interface.

The fracture resistance of the PEEK crown restorations was measured before and after aging. The mean fracture resistance was larger before aging since the PEEK material had a small modulus of elasticity, that allow material deformation to act as a stress breaker by reducing the forces transmitted to the abutment teeth, and it had a good wear resistance. The present study used a universal testing machine to apply a vertical load and spread stress more consistently between restorative material and dental tissues, thus reproducing normal occlusion[5,27,34,35].

The limitations of this study included the following: the application of a single load to produce failure did not reproduce clinical failures of the material as a step-stress accelerated life testing. Additionally, fractography was not performed in this study to evaluate the fracture surfaces. For future work, it is recommended to use fractography method to assess fracture surfaces of the material and a step-stress accelerated life test to reproduce clinical failures.

Within the limitations of this study, it was concluded that PEEK crown restorations fabricated by CAD/CAM methods could be safely recommended as an alternative prosthodontic material for fixed restorations. The techniques used in this study offered the advantage of high marginal accuracy and good fracture resistance for long-term performance in the oral environment.

PEEK showed promise as a material that can provide successful clinical outcomes.

Declaration

A. Almabadi was the sole contributor to this manuscript. The author had the idea, performed the experiments, collected of data, interpretated the results and wrote the manuscript.

Conflict of interest

The author declares no financial interest. Additionally, the author certifies that the submission is a self-funded original work and not under review at any other publication.

Data availability

Data are available upon request from the corresponding author.

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