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Two- and three-dimensional evaluation of marginal adaptation of occlusal veneers made with different materials and preparation designs

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Aim: The study assesses the effect of different restorative materials and preparation designs on the marginal adaptation of occlusal veneers measured using different methods.

Materials and Methods: 60 teeth were prepared to receive occlusal veneers made with three materials (milled and pressed PEEK and lithium disilicate) (20 samples each) and two preparation designs (anatomical and beveled) (10 samples each). After adhesion, samples were mechanically aged, and marginal gaps were evaluated visually using a stereomicroscope and digitally using reverse engineering software. The effect of their different variables on measured outcomes was analyzed using two-way ANOVA, and method agreement was analyzed using paired t-test, intra-class correlation coefficient, and Bland-Altman plot.

Results: There was a strong agreement between both methods of evaluation. There was also a significant difference between different materials, with milled PEEK having the best adaptation, followed by lithium disilicate, and pressed PEEK having the highest gaps. The effect of preparation designs was not statistically significant.

Conclusions: Milled PEEK had a superior marginal adaptation than Lithium disilicate. PEEK pressing procedure had a negative impact on marginal adaptation. Occlusal veneer preparation design does not affect marginal adaptation that affected the rate of alignment.

Keywords: PEEK, Glass-ceramics, Occlusal veneers, Marginal adaptation, Reverse engineering software.

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Introduction

The severe loss of coronal tooth structure in the form of wear can have a detrimental effect on oral function, teeth vitality, occlusal stability, and esthetics.[1] Since a significant portion of the coronary tooth structure is already lost when treating molars with occlusal wear, it is crucial to preserve dental tissues that are still present.[2] A full coverage extra coronal restoration that restores the damaged tooth structure requires significant additional tooth structure removal.[2]

Occlusal veneers are extra coronal restorations that require a more conservative preparation guided by interocclusal clearance and functional considerations.[3] The term occlusal veneer was introduced to adopt a conservative restoration of worn posterior teeth.[4] Lithium disilicate ceramics are considered the gold standard for the fabrication of occlusal veneers.[5] This is namely due to their durability, high adhesive properties, superior strength, and their ability to maintain such strength in smaller thicknesses.[6] However, their high modulus of elasticity may lead to excessive force transmission to the underlying dental structures, which in turn could adversely impact the biomechanical characteristics of both the restoration and the supporting tooth.[7]

Polyetheretherketone (PEEK) is a thermoplastic polymer classified under the polyaryletherketone group. The compound consists of an aromatic backbone molecular chain that is linked together by ketone and ether functional groups.[8] It has been used for the fabrication of dental implants,[9] fixed,[10] and removable[11] dental prostheses and endocrowns.[7] PEEK exhibits a modulus of elasticity of 4 GPa, which is comparable to that of human bone. Therefore, when utilized as a dental restoration, this material can function as a stress reliever, thereby diminishing the amount of force sent to both the restoration and the tooth it is supporting.[12] PEEK can be fabricated using one of two methods: heat pressing of pre-pressed pellets under vacuum using the lost wax technique or by milling of PEEK blanks, which are industrially pressed under standardized conditions of pressure and temperature.[13]

A planar occlusal preparation with a 1 to 1.5 mm clearance was deemed sufficient to achieve long-term success of occlusal veneer restorations.[14] Extending the tooth preparation to be the buccal surface can be a viable modification in cases of cervical carious lesions or for better esthetics.[15] The extension can be made in the form of beveling of the enamel margin, which is known to increase retention, improve esthetics, and enhance the sealing ability.[16]

Marginal adaptation of indirect restorations is crucial for the longevity of the restorations. Increased marginal discrepancies can result in a higher possibility of adhesive material exposure to oral fluids, which could lead to cement degradation and endanger tooth vitality.[17] There are many different methods of assessment of marginal adaptation, which can be categorized as either two-dimensional or three-dimensional based on the technology utilized. Contemporary computer-aided methods offer an improved evaluation of the restoration's adaptation.[18] These techniques provide more comprehensive and informative data in three dimensions. Another benefit of this approach is that it does not necessitate using a fit checker or several dies, thereby simplifying the process and increasing its reliability.[19]

This study was designed to test the effectiveness of PEEK made with different fabrication techniques as an alternative restorative material instead of lithium disilicate for occlusal veneers made with different preparation designs. The null hypothesis is that different materials and preparation designs have no effect on the marginal adaptation of occlusal veneers measured using different assessment methods.

Materials and methods

1- Sample selection:

The sample size was determined by setting an alpha (α) level at 0.05, a beta (β) level at 0.2, and using an effect size (f) of 0.524 based on the results from Ioannidis et al.,[20] the minimal total required sample size was calculated to be 54 samples. The sample size calculation was performed using R statistical analysis software version 4.4.0 for Windows.[21]

Sixty human mandibular first permanent molars extracted for periodontal reasons were collected from the outpatient clinic in the faculty of dentistry at Ain Shams University. They were inspected under 10x magnification using a magnifying lens (Optics Co., Ltd., China) for being intact, free of decay, and not restored. Calculus and soft tissue residues were removed using a hand scaler (Hu-Friedy, Chicago, ILs) and samples were disinfected using a 2% glutaraldehyde solution.

A digital caliper (SE 784EC, SE, China) was used to measure the mesio-distal dimensions of the teeth at the level of cemento-enamel junction. Teeth with an average mesio-distal dimension of (10.50 ± 0.50) (mm) and an average bucco-lingual dimension of (9.00±0.50) (mm) were selected. Any teeth below or above these values were excluded from the study. A difference of 0.5 mm was deemed acceptable for each measurement.[22]

2- Sample grouping:

Selected teeth were divided into three groups based on restorative material (i.e., 20 samples each)

Milled PEEK: Teeth received milled PEEK veneers.

Pressed PEEK: Teeth received pressed PEEK veneers.

Lithium disilicate: Teeth received lithium disilicate veneers.

Each group was then divided into two subgroups based on the preparation design (i.e., 10 samples each):

Anatomical: Teeth prepared using an anatomical preparation design.

Beveled: Teeth prepared using an anatomical preparation design with buccal and lingual cuspal bevels.

3- Teeth preparation:

Before preparation, all teeth were scanned using an Omnicam intraoral scanner (Dentsply Sirona, Bensheim, Germany) by a single experienced operator and were saved as STL files (Standard Tessellation Language) to serve as bio-copy for the final restorations. For preparation standardization, two indices were made for each sample before preparation by condensation silicon impression material (Zhermack SpA, Badia Polesine (RO), Italy), and all teeth were prepared by a single operator. The teeth were prepared using a high-speed turbine handpiece (350,000-450,000 RPM) (NSK / Nakanishi inc Japan) that was secured and adapted to a dental surveyor to be used during the preparation of each sample.

The occlusal reduction was set at 1 mm.[23] Using a tapered round-ended diamond bur (836 KR 314 018) (Komet, Lemgo, Germany) occlusal depth grooves were made following dental anatomy. These depth grooves were connected by removing enamel portions between them while preserving the approximate cusp inclination of 20°.

For the beveled groups, occlusal preparation was done initially in the same manner as the non-beveled groups; then, the buccal and lingual cusps were beveled using a diamond bur (No.893F.02314F) (Jota; Jota AG, Rüti, Switzerland). The bur was kept in a horizontal position to ensure that the bevel of the margins followed the contour of the bur's shape.[24]

After preparation, samples were finished with a fine-grit bur (8856 P 314 018) (3M ESPE, St. Paul, USA) then polished with abrasive rubber points (9608 314 030) (3M ESPE, St. Paul, USA) and abrasive discs

(Sof-lexTM) (3M ESPE, St. Paul, USA). Finally, the preparation thickness was verified using the previously acquired indices.

4- Restoration designing:

Prepared samples were re-scanned, and restoration design was carried out using CEREC inLab (inLab CAD Software; v.19.2) (Dentsply Sirona, Bensheim, Germany). The previously acquired scan was used as a bio-copy reference for the final restoration design.

5- Restoration fabrication:

A- Milling:

Samples were milled using inLab MC X5 (Dentsply Sirona, Bensheim, Germany). For milled PEEK, breCAM.BioHPP ø 98.5 x (Bredent GmbH, Germany) 12 mm blanks were used; for pressed PEEK, breCAM.wax ø 98.5 x (Bredent GmbH, Germany) 20 mm milling blanks were used, and for the lithium disilicate group, L12 IPS emax CAD (Ivoclar Vivadent Switzerland) blocks were used. PEEK blanks and wax blocks were dry milled, while IPS emax CAD blocks were wet milled.

B- Pressing:

Milled wax patterns were invested and burnt out for 60 minutes at 850 ºC following manufacturer instructions. The melt channel was filled with 5g of pressing pellets and was placed in the burnout furnace again for 20 minutes at 400 ºC. A creamy and uniform appearance verified the complete melting of the thermoplastic material. A disposable plunger was placed above the molten PEEK, and the ring was placed inside the pressing furnace (for 2 press) (Bredent GmbH, Germany). Pressing time under vacuum was set at 3 minutes under 2.3 bar pressure. After pressing, the restoration was left to cool under pressure for 35 minutes, following manufacturer instructions.

C- Crystallization:

Using an ultrasonic cleaner (Mickcara, China), milled lithium disilicate samples were cleaned, and then they were transferred to the pressing furnace (Programat P310) (Ivoclar Vivadent Switzerland) for the final crystallization cycle.

6- Restoration finishing:

Restorations were rinsed with tap water for 30 seconds, soaked in isopropyl alcohol (Isopropyl alcohol, ≥99.7%) (Sigma-Aldrich, St. Louis, MI, USA) for 10 minutes, and washed in an ultrasonic cleaner (Codyson Ultrasonic Cleaner CD-4820) (Codyson, China) (42,000 vibration/sec) with distilled water for 3 minutes. After air dryness, the occlusal surface was finished using low-speed polishing bur (Super-Snap) (Shofu, USA) The finished restorations were scanned using the intra-oral scanner following the same protocol used for the initial scanning to be used for 3D evaluation.

7- Adhesion:

A- Tooth structure surface treatment:

The enamel surface of prepared teeth was etched using 37% phosphoric acid (Meta etching gel) (META BIOMED CO., LTD) for 15 seconds, rinsed with a water spray for 20 seconds, and then air dried.

B- PEEK surface treatment:

The restorations were sandblasted with 110µm aluminum oxide at 2.5 bar with the nozzle placed nearly 45º and 3 cm from the restorations. A thin, uniform layer of bonding primer (visio.link) (Bredent GmbH, Germany) was placed on the internal surface of the restorations and was light cured using a light curing device (i-LED Plus Curing Light) (Guilin Woodpecker Medical Instrument Co., Ltd.) for 90 seconds following manufacturer instructions.

C- Lithium disilicate surface treatment:

The fitting surfaces of restorations were etched with 9.5% hydrofluoric acid (Ceram Etch) (Itena, France) for 20 seconds, rinsed thoroughly for another 60 seconds, and then dried. Silane coupling agent (SILAN-IT) (Itena, France) was applied to the fitting surface and was left to react for 60 seconds.

D- Cementation:

A dual-cured self-adhesive resin cement (Rely X unicem) (3M, USA) was applied to the fitting surface of the restoration and was cured for 20 seconds. The restoration was seated during cementation using a loading device with 1kg pressure applied to the central fossa of the restoration to minimize variations in pressure. Restorations after cementation and finishing procedures are presented in Figure 1.

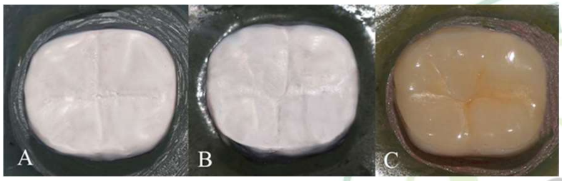

Figure 1: A) Milled PEEK occlusal veneer, B) Pressed PEEK occlusal veneer, C) Lithium disilicate occlusal veneer.

8- Aging:

Aging was performed using a CS-4.4 chewing simulator (Mechatronik Gmbh, Germany) which applies cyclic loading to the specimens. The cyclic loading process involved repeating the load application 250,000 times to simulate a one-year chewing condition clinically.[25] Each cycle of the chewing simulator replicates the mechanical forces experienced by the occlusal veneers during mastication, thus providing a realistic simulation of the wear and fatigue that would occur over one year of regular use.[25]

9- Marginal gap evaluation:

A- 2D evaluation:

Visual inspection of the marginal gap was done using a digital camera (DP10), mounted on a UC30 Stereo microscope (Olympus, Japan) at a magnification of 20X, as shown in Figure 2. Image analysis software (image j) (NIH, USA) was used to measure the vertical gaps at five points in each stereomicrograph after calibration. Consequently, measurements were conducted at 20 points for each specimen. Each specimen's mean vertical gap (in microns) was then calculated. The evaluation was performed by two observers, and the mean value of their readings was used for the final analysis.

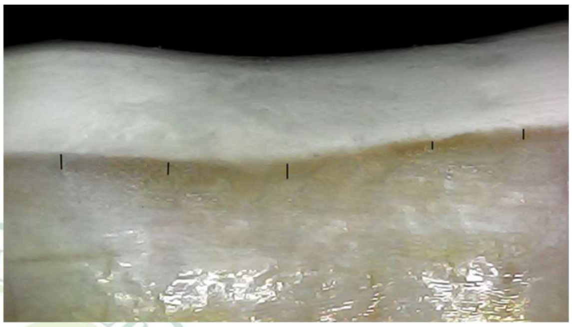

Figure 2: Evaluation of marginal gap under 20X magnification.

B- 3D evaluation:

The STL files of the prepared tooth and the finished restorations were imported to reverse engineering software Geomagic Control X 2018 (Geomagic, 3D systems, Morciville, NC, USA) Imported designs were trimmed to remove non-relevant data, and the two scans were superimposed using the "best-fit" algorithm (Figures 3A and 3B). The "3D compare" command was used to measure the marginal deviation of the restoration from the tooth. A color map with a maximum deviation range of 0.1 mm and -0.1 mm minimum deviation and no specific tolerance was drawn. "Green" donates a perfectly matching surface, "Red" donates the test model surface that was positively positioned relative to the reference model, and "Blue" donates the test model surface that was negatively positioned relative to the reference model (Figures 3C and 3D). After the scans' superimposition, the squared deviations between the two scans were calculated in three dimensions, and the root mean square values were calculated as the sum of these squares.

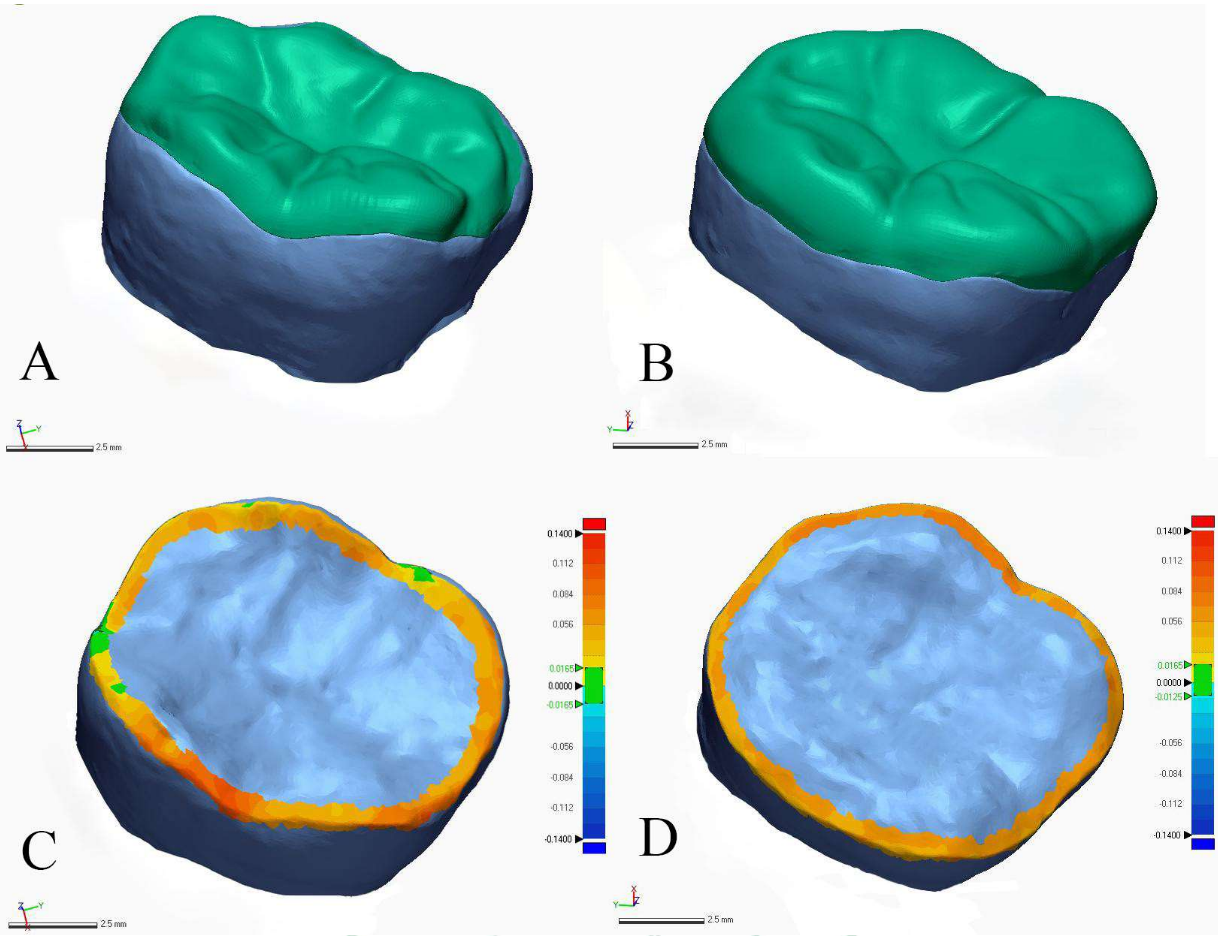

Figure 3: A) Best fit alignment of anatomical restoration, B) Best fit alignment of beveled restoration, C) Marginal deviation for anatomical restoration, D) Marginal deviation for beveled restoration.

11- Statistical analysis:

Numerical data were presented as mean values with 95% confidence intervals, standard deviation, and minimum and maximum values. The data were assessed for normality and variance homogeneity by examining the distribution and using Shapiro-Wilk's and Levene's tests for homogeneity of variances, respectively. The data were found to be normally distributed with homogeneous variances across groups and were analyzed using two-way ANOVA. Comparisons of main and simple effects were conducted using the pooled error term from the main ANOVA model, with adjustments for multiple comparisons made using the False Discovery Rate (FDR) method. Inter-observer and method reliability analyses were made using the intra-class correlation coefficient (ICC). Method agreement was analyzed using a paired t-test and the Bland-Altman plot. The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.4.0 for Windows.[21]

Results

Descriptive statistics are presented in Table 1 and in Figures 4 and 5. There was a strong agreement between both observers [ICC (95% CI) = 0.922 (0.810:1)] that was statistically significant (p<0.001). Results of the two-way ANOVA presented in Table 2 showed that only the type of material had a significant effect on the marginal gap for both assessment methods (p<0.001). However, the effect of the preparation design and its interaction with material type was not statistically significant.

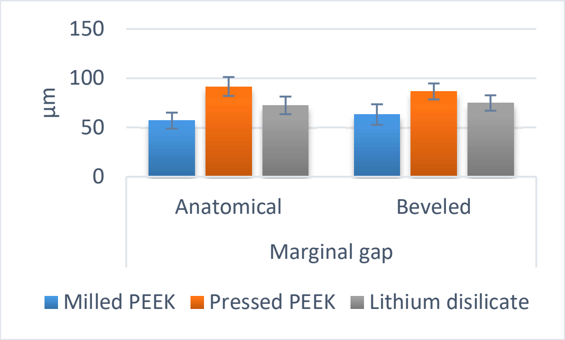

Figure 4: Bar chart showing the marginal gap's mean and standard deviation values.

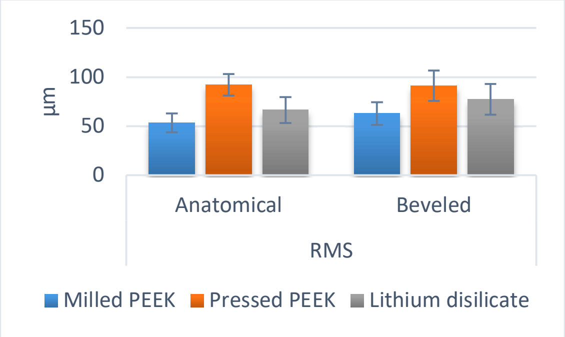

Figure 5: Bar chart showing RMS's mean and standard deviation values.

Table 1: Descriptive statistics.

Measurement	***Material***	***Preparation design***	***Mean***	***95% CI***		***SD***	***Min.***	***Max.***
				Lower	***Upper***			
Marginal gap (µm)	***Milled PEEK***	***Anatomical***	56.81	51.79	61.83	8.10	45.02	73.91
		Beveled	63.12	56.74	69.50	10.30	41.19	76.82
	Pressed PEEK	***Anatomical***	91.56	85.55	97.56	9.69	77.21	106.10
		Beveled	86.52	81.47	91.56	8.14	76.72	105.61
	Lithium disilicate	***Anatomical***	72.38	66.89	77.87	8.86	59.05	86.64
		Beveled	74.83	69.97	79.68	7.83	61.12	89.30
RMS (µm)	***Milled PEEK***	***Anatomical***	53.31	47.35	59.26	9.61	32.99	69.36
		Beveled	62.81	55.64	69.99	11.58	44.39	75.96
	Pressed PEEK	***Anatomical***	92.02	85.19	98.85	11.02	71.28	110.05
		Beveled	91.14	81.53	100.75	15.51	62.60	115.08
	Lithium disilicate	***Anatomical***	66.33	58.06	74.60	13.35	46.37	88.79
		Beveled	77.15	67.44	86.86	15.67	52.57	99.07

CI Confidence interval, SD Standard deviation, Min. Minimum, Max. Maximum

Table 2: The effects of different variables on marginal adaptation.

Measurement	***Parameter***	***Sum of squares***	***df***	***Mean square***	***f-value***	***p-value***
Marginal gap (µm)	***Material***	8463.28	2	4231.64	**53.86**	**<0.001***
	Preparation design	22.98	1	22.98	**0.29**	**0.591**
	Material* preparation design	332.79	2	166.40	**2.12**	**0.130**
RMS (µm)	***Material***	11361.10	2	5680.55	**33.69**	**<0.001***
	Preparation design	630.27	1	630.27	**3.74**	**0.058**
	Material* preparation design	411.10	2	205.55	**1.22**	**0.304**

df degree of freedom, *significant (p<0.05).

Pairwise comparisons for the effect of material were all statistically significant, with milled PEEK samples having the best adaptation, followed by lithium disilicate samples, and pressed PEEK having the least adaptation. The agreement analysis presented in Table 3 showed no significant difference between both methods and that they had a strong statistically significant agreement. The Bland-Altman plot presented in Figure 6 indicates strong agreement between the two measurement methods, with most differences near zero (i.e., purple region) and most points within the acceptable limits of agreement (i.e., green for upper and red for lower), showing minimal systematic bias. Only one outlier was noted. Additionally, the consistent spread of differences across various mean values suggests an absence of proportional bias, confirming the reliability of the methods across different measurement ranges.

Table 3: Assessment method agreement

(Mean±SD)		*Mean difference (95% CI)*	*t-value*	*p-value*	*ICC (95% CI)*
2D evaluation	*3D evaluation*				
74.20±14.88	73.79±19.09	**0.41 (-2.76:3.58)**	**0.26**	**0.797**	**0.855 (0.758:0.913)***

CI Confidence Interval, *Significant (p<0.05).

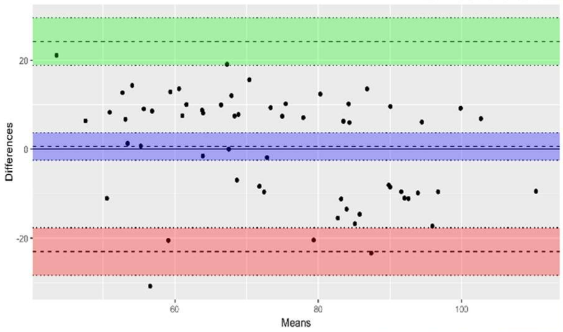

Figure 6: Bland-Altman plot.

Discussion

Occlusal veneers are considered a conservative alternative to full coverage restorations in cases of vertical dimension loss.[3] They are traditionally made using monolithic ceramics due to their ability to withstand occlusal forces even when fabricated in thin thicknesses.[26] However, they tend to have higher rigidity, which may lead to excessive force transmission to the remaining tooth structure.[7]

In this study, there was a strong agreement and correlation between digital and optical measurements. This finding agreed with multiple studies[27–30] that found no difference in measurement accuracy between digital and conventional assessment methods of marginal adaptation. Digital techniques should serve as dependable substitutes for traditional methods in evaluating the marginal fit of fixed dental restorations.[31]

The digital method used for marginal gap evaluation utilizing reverse engineering software resulted in an average of 57,000 measurement points for marginal adaptation. Collecting this volume of data points would be unfeasible using traditional non-digital measurement methods. Unlike other programs that use surface or mesh distance comparisons, Geomagic Control X is a widely used, accurate 3D analysis tool that enables 3D comparison. Additionally, it offers customization options based on the object being measured and its clinical relevance, allowing for flexibility in customizing the color map, which extends a feature that other software lacks.[32]

All samples were mechanically aged to simulate a one-year clinical service. All the measured gap values in this study were below the 120 µm threshold for the maximum clinically acceptable marginal gap as devised by McLean and von Fraunhofer.[33] This indicates that aging did not negatively impact the marginal adaptation of the various tested materials, as they were able to achieve clinically acceptable results regardless. However, the null hypothesis was partially rejected, as it was found that the type of material had a significant effect on measured gap values.

Results showed that regardless of preparation design, marginal gap values were highest in pressed PEEK samples, followed by lithium Disilicate, and the lowest gap values were found in milled PEEK samples, with all pairwise comparisons being statistically significant. This result was in agreement with Nagi et al.[34] and Osman et al.[35] who reported better marginal adaptation of milled PEEK in comparison to lithium disilicate, which could be attributed to easier machinability, the higher penetration rate of cutting bur of polymer-based materials, and the high brittleness of glass-based ceramics that make them more liable to marginal chipping during finishing.[36,37]

In contrast, other studies reported better marginal adaption of lithium disilicate, such as the one by Godil et al.,[38] who found that restorations made from lithium disilicate exhibited fewer marginal and internal discrepancies than those made from PEEK. The contradiction in results may be due to the use of ivorine teeth in that study, which are inherently different in structure from natural teeth, making the results less reliable in recreating the clinical situation. Additionally, in that study, a single estimation method was used, unlike in our study, where two methods of marginal gap assessments confirmed the results.

Results also showed that marginal gaps formed with pressed restorations were significantly higher than those in milled PEEK and lithium disilicate restorations. This might be due to the preheating method, the use of a vacuum pressing device, and the dimensional changes associated with the investing procedure, which is operator-dependent. This finding was in agreement with Attia et al.[39] and Attia and Shokry,[40] who concluded that pressed PEEK restorations had significantly higher gap values than milled restorations.

In our study, preparation design did not affect the measured marginal gap regardless of the material used, which was in agreement with the findings of multiple studies[14,23] that found no significant effect of preparation design on the marginal adaptation of occlusal veneers.

Despite our efforts to simulate intraoral conditions as closely as possible, it is important to acknowledge the inherent limitations of in vitro studies, including the challenge of fully replicating the complex dynamics of the oral environment. Consequently, while our findings offer initial insights into the effectiveness of PEEK occlusal veneers, further in vivo studies and randomized controlled trials are essential to evaluate the long-term performance and clinical success of these restorations.

Conclusions

Within the limitations of this in vitro study, the following conclusions were drawn:

1- Milled PEEK veneers had a significantly better marginal adaptation than lithium disilicate.
2- PEEK fabrication method significantly affected the marginal gap, with milled restorations having significantly better marginal adaptation.
3- Preparation design had no significant effect on the marginal gap.

FUNDING:
The study was self-funded.

DATA AVAILABILITY:
Data are available upon request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE:
Approval for the usage of unidentified pooled human teeth was acquired from the ethics committee of the faculty of dentistry at Ain Shams University (approval no. 130–16 UE).

COMPETING INTERESTS:
The authors declare that they have no competing interests.

References

1. Smith BG, Knight JK. A comparison of patterns of tooth wear with aetiological factors. British Dental Journal. 1984 Jul 7;157(1):16–9.
2. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for anterior teeth. Journal of Prosthetic Dentistry. 2002;87(5):503–9.
3. Dietschi D, Argente A. A comprehensive and conservative approach for the restoration of abrasion and erosion. Part I: concepts and clinical rationale for early intervention using adhesive techniques. The European journal of esthetic dentistry official journal of the European Academy of Esthetic Dentistry. 2011;6(1):20–33.
4. Magne P, Schlichting LH, Maia HP, Baratieri LN. In vitro fatigue resistance of CAD/CAM composite

resin and ceramic posterior occlusal veneers. Journal of Prosthetic Dentistry. 2010;104(3):149–57.

5. Alghauli M, Alqutaibi AY, Wille S, Kern M. Clinical outcomes and influence of material parameters on the behavior and survival rate of thin and ultrathin occlusal veneers: A systematic review. Journal of Prosthodontic Research. 2023;67(1):45–54.

6. Abd Elmonem, E., abo el fadl, A., hamdy, A. effect of Preparation Design effect on Emax Occlusal Veneers fracture resistance. Ain Shams Dental Journal, 2023; 31(3): 22-28. doi: 10.21608/asdj.2022.103482.1081

7. Zoidis P, Bakiri E, Polyzois G. Using modified polyetheretherketone (PEEK) as an alternative material for endocrown restorations: A short-term clinical report. Journal of Prosthetic Dentistry. 2017;117(3):335–9.

8. Koganesawa M, Yamamoto S, Kaneko R, Toyama D, Ikeda H, Isoyama K. Utility of the attached sample blood for quality control of long-Term cryopreserved umbilical cord blood for hematopoietic cell transplantation. Journal of the Showa Medical Association. 2016;76(2):199–206.

9. Schwitalla A, Müller WD. PEEK Dental Implants: A Review of the Literature. Journal of Oral Implantology. 2013 Dec 11;39(6):743–9.

10. Stawarczyk B, Beuer F, Wimmer T, Jahn D, Sener B, Roos M, et al. Polyetheretherketone - A suitable material for fixed dental prostheses? Journal of Biomedical Materials Research - Part B Applied Biomaterials. 2013 Oct;101(7):1209–16.

11. Zoidis P, Papathanasiou I, Polyzois G. The Use of a Modified Poly-Ether-Ether-Ketone (PEEK) as an Alternative Framework Material for Removable Dental Prostheses. A Clinical Report. Journal of Prosthodontics. 2016 Oct;25(7):580–4.

12. Rzanny A, Gobel F, Fachet M. BioHPP summary of results for material tests. JENA University Hospital. 2013;

13. STAWARCZYK B, EICHBERGER M, UHRENBACHER J, WIMMER T, EDELHOFF D, SCHMIDLIN PR. Three-unit reinforced polyetheretherketone composite FDPs: Influence of fabrication method on load-bearing capacity and failure types. Dental Materials Journal. 2015 Jan 30;34(1):7–12.

14. Sirous S, Navadeh A, Ebrahimgol S, Atri F. Effect of preparation design on marginal adaptation and fracture strength of ceramic occlusal veneers: A systematic review. Clinical and Experimental Dental Research. 2022;8(6):1391–403.

15. Christensen GJ. Considering tooth-colored inlays and onlays versus crowns. Journal of the American Dental Association. 2008;139(5):617–20.

16. Patanjali S, Arora A, Arya A, Grewal MS. An in vitro study of effect of beveling of enamel on microleakage and shear bond strength of adhesive systems in primary and permanent teeth. International journal of clinical pediatric dentistry. 2019;12(3):205.

17. Dalloul R, Nassar JA, Al-Houri N. A Comparative Study of Marginal Fit between IPS e.max Press Crown and Endocrown after Cementation (In Vitro). Clinical Medicine and Diagnostics. 2016;6(5):122–5.

18. Moldovan O, Luthardt RG, Corcodel N, Rudolph H. Three-dimensional fit of CAD/CAM-made zirconia copings. Dental Materials. 2011;27(12):1273–8.

19. Bosch G, Ender A, Mehl A. A 3-dimensional accuracy analysis of chairside CAD/CAM milling processes. The Journal of prosthetic dentistry. 2014;112(6):1425–31.

20. Ioannidis A, Park JM, Hüsler J, Bomze D, Mühlemann S, Özcan M. An in vitro comparison of the marginal and internal adaptation of ultrathin occlusal veneers made of 3D-printed zirconia, milled zirconia, and heat-pressed lithium disilicate. The Journal of Prosthetic Dentistry. 2022;128(4):709–15.

21. R Core Team. R: A Language and Environment for Statistical Computing [Internet]. Vienna, Austria: R Foundation for Statistical Computing; 2023. Available from: https://www.R-project.org/

22. Aziz KHA, Aziz AA, Salleh H, Ambak NJ, Rahman NHA, Oo SS, et al. Validation of a new questionnaire assessing the health impact of divorce on women: An exploratory factor analysis. Malaysian Journal of Public Health Medicine. 2016;16:64–71.

23. Angerame D, De Biasi M, Agostinetto M, Franzò A, Marchesi G. Influence of preparation designs on marginal adaptation and failure load of full-coverage occlusal veneers after thermomechanical aging simulation. Journal of Esthetic and Restorative Dentistry. 2019;31(3):280–9.

24. Aliaga J, Hermoza-N M. Stress distribution in occlusal veneers with different finish lines when applying vertical and tangential forces. Odovtos International Journal of Dental Sciences. 2022;24(3):103–14.

25. Naumann M, Sterzenbach G, Pro P. Evaluation of Load Testing of Postendodontic Restorations In Vitro : Linear Compressive Loading , Gradual Cycling Loading and Chewing Simulation. 2005;829–34.

26. Koubi S. Worn dentition; The Full mock up concept - StyleItaliano [Internet]. Jul 27. 2016 [cited 2018 Dec 3]. Available from: https://styleitaliano.org/worn-dentition-the-full-mock-up-concept/

27. Park JY, Bae SY, Lee JJ, Kim JH, Kim HY, Kim WC. Evaluation of the marginal and internal gaps of three different dental prostheses: Comparison of the silicone replica technique and threedimensional superimposition analysis. Journal of Advanced Prosthodontics. 2017;9(3):159–69.

28. Cunali RS, Saab RC, Correr GM, Cunha LF da, Ornaghi BP, Ritter AV, et al. Marginal and internal adaptation of zirconia crowns: a comparative study of assessment methods. Brazilian Dental Journal. 2017;28:467–73.

29. Schlenz MA, Vogler JAH, Schmidt A, Rehmann P, Wöstmann B. Chairside measurement of the marginal and internal fit of crowns: a new intraoral scan–based approach. Clin Oral Invest. 2020 Jul;24(7):2459–68.

30. Rudolph H, Ostertag S, Ostertag M, Walter MH, Luthardt RG, Kuhn K. Reliability of light microscopy and a computer-assisted replica measurement technique for evaluating the fit of dental copings. Journal of Applied Oral Science. 2018;26:e20160590.

31. Mai HY, Lee WK, Kwon TG, Lee DH. Reliability of digital measurement methods on the marginal fit of fixed prostheses: A systematic review and meta-analysis of in vitro studies. The Journal of prosthetic dentistry. 2020;124(3):350-e1.

32. Jeong YG, Lee WS, Lee KB. Accuracy evaluation of dental models manufactured by CAD/CAM milling method and 3D printing method. The journal of advanced prosthodontics. 2018;10(3):245.

33. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J. 1971 Aug 3;131(3):107–11.

34. Nagi N, Fouda AM, Bourauel C. Comparative evaluation of internal fit and marginal gap of endocrowns using lithium disilicate and polyether ether ketone materials - an in vitro study. BMC Oral Health. 2023 Apr 7;23(1):207.

35. Osman AM, El Mahallawi OS, Khair-Allah LS, El Khodary NA. Marginal integrity and clinical evaluation of polyetheretherketone (PEEK) versus lithium disilicate (E-Max) endocrowns: Randomized controlled clinical trial. International Journal of Health Sciences. 2022;(IV):1831–45.

36. Makky MR, Shokry TE, Metwally MF. Comparison of marginal and internal fit of Copings fabricated from Polyetheretherketone and Zirconia: an in-vitro study. Al-Azhar Journal of Dental Science. 2020;23(4):355–62.

37. Hasanzade M, Sahebi M, Zarrati S, Payaminia L, Alikhasi M. Comparative evaluation of the internal and marginal adaptations of CAD/CAM endocrowns and crowns fabricated from three different materials. Int J Prosthodont. 2021;34(3):341–7.

38. Godil AZ, Kazi AI, Wadwan SA, Gandhi KY, Dugal RJ. Comparative evaluation of marginal and internal fit of endocrowns using lithium disilicate and polyetheretherketone computer-aided design-computer-aided manufacturing (CAD-CAM) materials: An: in vitro: study. Journal of Conservative Dentistry and Endodontics. 2021;24(2):190–4.

39. Attia MA, Blunt L, Bills P, Tawfik A, Radawn M. Micro-CT analysis of marginal and internal fit of milled and pressed polyetheretherketone single crowns. The Journal of Prosthetic Dentistry. 2023;129(6):906-e1.

40. Attia MA, Shokry TE. Effect of different fabrication techniques on the marginal precision of polyetheretherketone single-crown copings. The Journal of Prosthetic Dentistry. 2020;124(5):565-e1.