Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/jptcp.v29i03.6408

MARGINAL ADAPTATION OF TWO TYPES OF MONOLITHIC PRESSABLE CROWNS SUPPORTED BY DIFFERENT IMPLANT ABUTMENTS AFTER THERMO-MECHANICAL FATIGUE

Zainab R. El Sharkawy[1*], Ayat G. Montaser[2], Suad M. Hassan[3], Asmaa Abdelgawad[4], Fatma M. Abdel-Rahman[5], Inas M. Mohamed[6], Ashraf Marawan El Azzazy[7]

[1*]Assistant professor of Crowns and Bridges Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt. E-mail: ZainabElSharkawy.26@azhar.edu.eg
[2]Lecturer of Crowns and Bridges Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt. E-mail: Ayatmontaser786@gmail.com
[3]Assistant professor of Crowns and Bridges Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt. E-mail: dr.suadmohamed@gmail.com
[4]Lecturer of Crowns and Bridges Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt. E-mail: Semsemaabdelgawad@yahoo.com
[5]Lecturer of Dental Biomaterials Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt. E-mail: fatma.dent.sc@gmail.com
[6]Lecturer of Dental Biomaterials Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt. E-mail: Enasalsherbiny@gmail.com
[7]Lecturer of Dental Biomaterials Department, Faculty of Dental Medicine, Assiut, AL Azhar University, Egypt. E-mail: drashrafmarawan@gmail.com

***Corresponding Author:** Zainab R. El Sharkawy
*Assistant professor of Crowns and Bridges, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt. e-mail: ZainabElSharkawy.26@azhar.edu.eg

Abstract
Purpose: Poly-ether-ether-ketone (PEEK) is a sole polymer material that has recently been introduced to dentistry; marginal gap is increased significantly after thermomechanical fatigue (TF) as well as cement dissolution and, lastly failure of restoration. The current research aimed to evaluate the marginal adaptation of two kinds of monolithic pressable crowns supported by different implant abutments after thermo-mechanical fatigue.

Materials: Blocks of epoxy resin were used to insert twenty – eight titanium dummy implants and allocated into 2 groups according to type of implant abutments (n=14): titanium implant abutments group (Ti) and ceramic-reinforced poly-ether-ether-ketone implant abutments group (PEEK). Every group was then subdivided into 2 subgroups (n = 7) in accordance with the kind of crowns: monolithic lithium disilicate "IPS e.max Press" crowns subgroup (EP) and monolithic ceramic reinforced poly-ether-ether-ketone (BioHPP Granulates) crowns subgroup (BG). All crowns were fabricated by means of the pressing technique. After surface treatments, adhesive cementation was performed for all crowns. The samples were subjected to thermomechanical fatigue (TF). Marginal adaptation was measured before and after thermomechanical fatigue by means of a digital stereomicroscope.

Results: PEEK group recorded lower marginal gap mean scores prior and following thermomechanical fatigue (29.06±7.84µm) (39.70±12.00µm) respectively compared to Ti group

(41.57±8.82μm) (51.02±12.53μm) respectively. (EP) recorded lower marginal gap mean scores compared to (BG) prior and following thermomechanical fatigue in both different implant abutments.

Conclusions: For all tested materials, the marginal gap mean scores documented in the current research were within the limits of standards that are deemed appropriate by clinicians.

Keywords: Ceramic-reinforced PEEK (BioHPP); IPS e.max Press; Margin adaptation; PEEK implant abutment; Titanium abutment; Thermomechanical fatigue.

Introduction

Dental implants became widely established as one of the treatment modalities to replace lost teeth [1]. The selection of the appropriate abutment is therefore critical for mechanical stability and cosmetic restoration [2].

Titanium implant abutment is considered the standard treatment. There are cosmetic complications due to its metallic colors, especially in the case of the delicate gingival biotype. So, a variety of abutments that vary in design and biomaterials have been developed to attain the best mechanical, biological and cosmetic treatment results [3].

PEEK (poly-ether-ether-ketone) implant abutment is a high performance semi-crystalline linear thermoplastic, aromatic and polycyclic polymer. PEEK characterized by its biocompatibility and look like real tooth color as opposed to metal restorations [4].

BioHPP (Biocompatible High Performance Polymer) comprises 20% of the filler particles in the PEEK polymer matrix, which are isolated ceramic grains having a grain volume ranging from 0.3–0.5 μm. The relatively low elasticity modulus (3–4 Gpa) is comparable to that found in human bone is the main benefit of this material. Where it reduces the force that occurs on the bone [5].

Lithium disilicate glass ceramic restorations (IPS e.max Press) were utilized like a cosmetic super-structure above implants and are recognized due to their exceptional mechanical strength as well as translucency, biocompatibility and chemical steadiness [6].

PEEK superstructure above implants can deliver dense production in the fabrication of crowns and bridges. It is a biocompatible material which offers excellent dimension consistency and strong resilience to both mechanical and chemical wear [7].

PEEK and IPS e.max are accessible like a press-fit ingot or as a block that can be milled. Heat-pressed restorations have superior occlusal precision, marginal adaption, and excellent cosmetics. It is obtained by means of a lost-wax technique, with ingots having the preferred final shade and mechanical properties [8].

Regarding the sustained efficacy of implant-supported restorations, the accurate fit of the superstructure to the implant abutment is critical [9]. Since PEEK has been recently used in dental prosthetics as implant abutments and crown restorations. There was a necessity to assess the marginal fit of PEEK granulates compared to IPS e.max Press crowns on different implant abutments (titanium and PEEK) and thus the current study was performed.

Materials and methods

Sample size calculation

Based on preceding research and by means of a power analysis program, the whole size of samples 28 (14 in each group were subdivided to 7 in each subgroup) was adequate because the size of samples (7) within every subgroup has an 80% power to notice a variation amongst means of 169.87 at 95% confidence intervals and a significance level (alpha) of 0.05 (two-tailed). The p-value was below 0.05 (two-tailed) within 80% (the power) of these surveys, indicating the statistical significance of the outcomes. While the residual 20% of investigations, The statistical significance of the mean differences was not established (data generated via StatMate 2.00 on GraphPad) [9].

Factorial design

A total of twenty-eight titanium dummy implants were divided into 2 groups (n=14) based on the kind of implant abutment: group (Ti) and group (PEEK). Every group was then subdivided into 2 subgroups (n = 7) in accordance with the kind of crowns: monolithic lithium disilicate "IPS e.max Press" crowns subgroup (EP) and monolithic ceramic reinforced poly-ether-ether-ketone (BioHPP Granulates) crowns subgroup (BG).

1- Manufacturing of master models

The dummy implants (Nobel Biocare, USA) (Size (Ø 4.3mm, L 13mm)) were inserted (2 cm in length &1.5 cm in width) into the epoxy resin's core leaving 2mm below its neck.

2- Connection of implant abutments

Titanium and PEEK abutments (SKY implant, Bredent UK, Germany) (size (Ø 4.3mm, L 9mm)) representing maxillary second premolar were squeezed and tightened to the matching dummy implants at 25 N/cm in accordance with the producer's commands by means of torque wrenches. Then teflon tupe and fluid composite (Nova flowable composite, Istanbul) were poured into the screw hollows.

3- Crown fabrications (Fig. 1)

Fabrication of 28 identical fully anatomical wax patterns (Acwws616B, Muenster, Germany**)** crowns of permanent maxillary second premolar for both groups by using a CAD/CAM CHERA ECO 5-axis dental milling machine (CHERA, eco-mill 5x, Germany) was used for the fabrication of pressed crowns.

The fully anatomical wax pattern design was shaped, including a 30mm die spacer and the external shape of all wax patterns was standardized in their length (11mm) and breadth (8.5mm). A shoulder margin was used in accordance with the abutment manufacturing [10].

a. Monolithic lithium disilicate "IPS e.max Press" (EP) crown fabrication

Fourteen (EP) crowns were fabricated by: an IPS silicon ring filled via IPS e.max special investment substance (IPS Press Vest, Ivoclar Vivadent, Liechtenstein, Germany); then a preheated burn-out furnace (IBEX**,** Richardson, USA) to remove wax patterns. After that pressing procedure, the corresponding (EP) ingot was inserted, followed by the ALOX plunger in the center of the Zubler furnace (Zubler Vario Press 300, Germany). After divesting the crowns, glaze the crowns using glaze paste material (Ivoclar Vivadent, Germany).

b. Monolithic BioHPP Granulates crown fabrication

Fourteen BioHPP Granulate crowns were fabricated via the heat-pressing method, which is a similar process utilized in the fabrication of (EP) crowns, with the subsequent exception that the investment substance was Brevest for 2 Press (For2press, Bredent, Germany).

c. Checking the crowns’ seating on the abutments

Utilizing a USB digital microscope (Optic Co., Beijing, China) (X)=10, each crown was installed on the die and its full sitting was verified. If a little nodule or flaw was found, the crown was rejected.

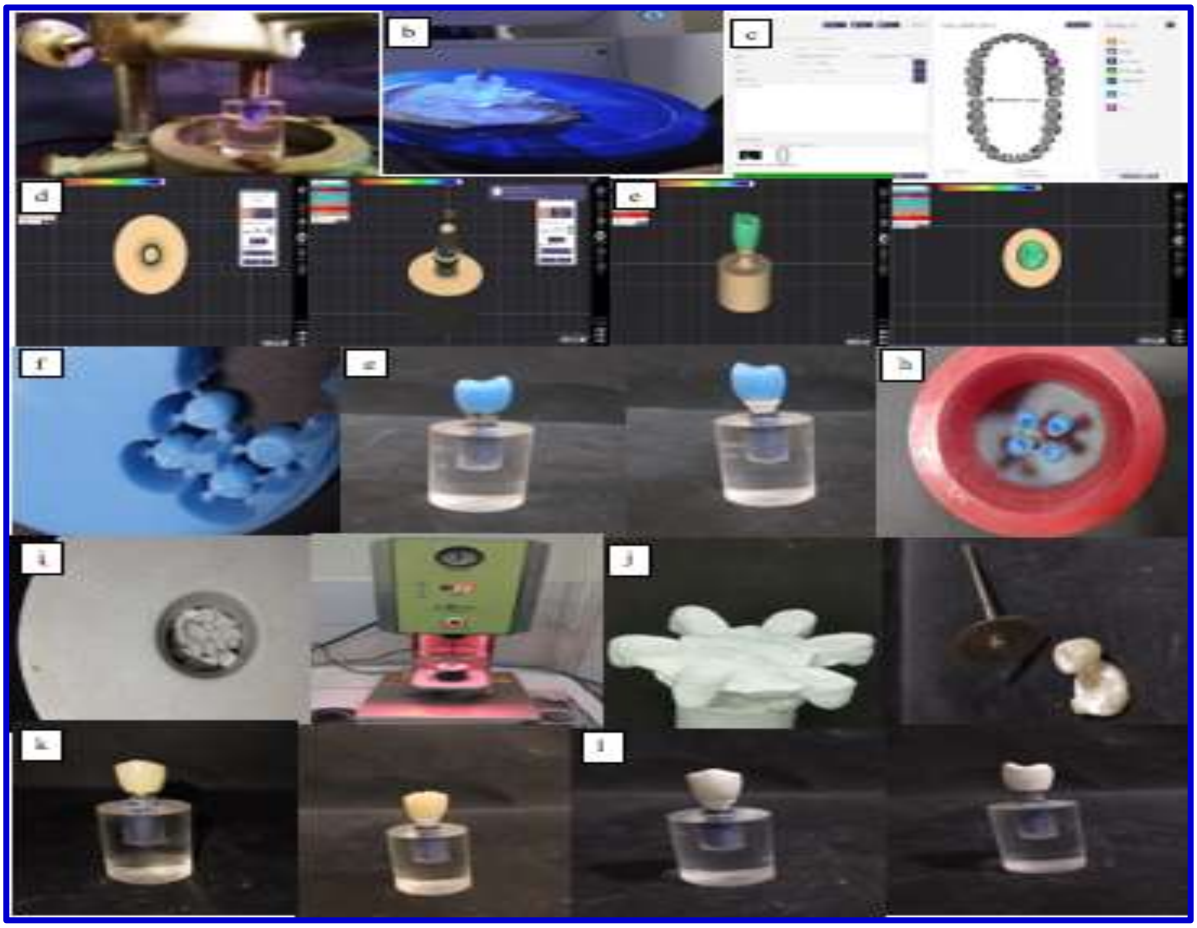

Figure 1: a: The dummy implant embedded in the epoxy resin, b: Scanning process, c: Choosing crowns from new dialogue box, d: Tracing the margin of abutment, e: Finished design of monolithic crown sample, f: Milling wax crown, g: Milling wax crowns were fitted on abutment, h: Spruing wax patterns inside investment silicon ring, i: Pressing procedure, j: Divesting procedure and Finishing, k: Final IPS.e.max press crown, l: Final BioHPP PEEK crown.

4- Cementation of the restorations

Before cementation of the restoration, appropriate surface treatment of every crown was performed as per the producer's commands, as shown in (Table 1). The crowns were cemented by means of adhesive resin cement (Panavia F2.0, Kuraray Noritake Dental) under 50-N continuous stress for 5 minutes [11].

Table 1 Surface treatment of implant abutments & crowns superstructure.

Material	Restoration	Surface treatment
Titanium	**Implant abutment**	Airborne particles abrasion 110µ Al_2O_3 at 2 bar from 15mm distance for 10s. b. Residual particles were cleaned by using an ultrasonic bath containing 96% ethanol for ten minutes. c.Application of metal primer was done, then it air dried for 30s.
Ceramic - reinforced PEEK	**Implant abutment**	Exposed to 2-bar pressure,15-mm distance and 110 µm Al_2O_3 sandblasting for 10s. b. For ten minutes, debris particles were ultrasonically polished using 96% ethanol. c. The PMMA primer combination "Visio.link" and a unique composite were applied for 10s, and the polymerization process took 90.
Lithium disilicate reinforced glass ceramic	**Crown**	Etching via hydrofluoric acids 9.5% for 20s, washed for 60s and air dried. b. Air drying followed the 30s application of porcelain primer.
Ceramic - reinforced PEEK	**Crown**	Air abrasion using aluminum oxide (110 µm) at 2 bar pressure at 3 cm distance. b. After one minute of ultrasonic cleaning with distilled water, the crowns were carefully air dried. c. After applying one coat of single bond adhesive, the reaction was given 20s to happen.

5- Marginal gap determination before thermo-mechanical fatigue

The marginal adaptation was assessed by evaluating the gap width amongst the crown margin and the finish line of the implant abutment utilizing a digital image analysis system (Image J 1.43U, National Institute of Health, USA) in four locations on the buccal, lingual, mesial, and distal surfaces at an established magnifying of 40X. Three repetitions of the measurement were made at every location.

6- Thermo-mechanical fatigue procedure

Mechanical aging via cyclic loading was carried out with an apparatus that was controlled by programmable logic; The recently created four-station multifunctional ROBOTA chewing simulator (ACH-09075DC-T, AD-Tech Technology, Germany) used a servomotor for operation and was incorporated into a thermo-cyclic procedure. Five kilograms of weight, or 49 N of chewing force, was applied. To imitate the 6-month chewing situation clinically, repetition the test procedure 75,000 times [12].

7- Marginal gap determination after thermo-mechanical fatigue

After thermo-mechanical fatigue, the marginal gaps of every sample were determined at similar predetermined points (formerly marked) for each tested sample.

Statistical analysis

Statistics organization and statistical analysis were completed utilizing the Statistical Package for Social Sciences (SPSS) version 20. Numerical data were concise utilizing mean, standard deviation, median and range. By inspecting the distribution of the data and applying the Kolmogorov-Smirnov and Shapiro-Wilk tests, the normality of the data was investigated. Every p-value has two sides. P-values ≤0.05 were regarded as significant.

Results:

❖ **Effect of implant abutment types (regardless of crown types)**

- The outcomes of the independent t test showed that the implant abutment types had a statistically significant effect on marginal gap mean values.
- Lower marginal gap mean values were recorded in (PEEK) before and after (TF) (29.06±7.84µm) (39.70±12.00µm) respectively compared to (Ti) (41.57±8.82µm) (51.02±12.53µm) respectively with a significantly higher value recorded in (Ti) before (*P=0.001*) and after *(P=0.02*). However, the percentage of change (from before to after) did not show a significant difference (P=0.13) among (Ti) and (PEEK) **(Table 2** & **Fig. 2)**.

Table 2 Comparative analysis and statistical description of mean value before, after and percentage of change between groups (regardless of subgroups).

		Mean	Std. Dev	Median	P value
Before thermomechanical fatigue	**Group (Ti)**	41.57	8.82	42.07	0.001*
	Group (PEEK)	29.06	7.84	27.47	
After thermomechanical fatigue	**Group (Ti)**	51.02	12.53	47.39	0.022*
	Group (PEEK)	39.70	12.00	37.71	
Percent change	**Group (Ti)**	23.83	21.65	21.38	0.13 ns
	Group (PEEK)	37.75	27.83	36.18	

Ti, titanium; PEEK, Poly-ether-ether-ketone;
Significance level P≤0.05, *significant, ns=non-significant

❖ **Effect of crown types (regarding implant abutment types)**

- **Group (Ti) implant abutment:** Lower marginal gap mean values were showed in (EP) either before or after (TF) (38.24±11.66µm) (42.91±8.64µm) respectively compared to (BG)

(44.89±2.66µm) (59.13±10.59µm) respectively. The variation was statistically non-significant amongst subgroups (*P= 0.167*) before (TF). While after thermomechanical fatigue, a significantly greater value was showed in (BG) (*P=0.009*) **(Table 3** & **Fig. 2).**

- **Group (Peek) implant abutment:** Lower marginal gap mean values were recorded in (EP) either before or after (TF) (22.75±2.92µm) (30.47±6.22µm) respectively compared to (BG) (35.38±5.63µm) (48.93±8.63µm) respectively. A significantly higher value was recorded in (BG) either before or after (TF) (*P=0.001*) (*P=0.001*) respectively **(Table 3** & **Fig. 2).**
- The marginal gap mean values increased in all subgroups after (TF). However, the marginal gap mean values for both groups were between ranges that were deemed clinically appropriate [8, 12].

Regarding the percent increase in marginal gap after (TF) in both groups (Ti and PEEK), higher mean percent rise was seen in (BG) than (EP) with a non- statically significant variation among them (*P*=0.08) (*P*=0.74) respectively (**Table 3)**.

Table 3 Comparative analysis and statistical description of mean value before, after and percentage of change between subgroups within each group.

Groups		Subgroups	Mean	Std. Dev	Median	*P* value
(Ti)	**Before (TF)**	(EP)	38.24	11.66	38.26	0.16 ns
		(BG)	44.89	2.66	44.38	
	After (TF)	(EP)	42.91	8.64	40.60	0.009*
		(BG)	59.13	10.59	59.97	
	Percent change	(EP)	16.15	20.85	3.27	0.08 ns
		(BG)	31.50	21.05	36.48	
(PEEK)	**Before (TF)**	(EP)	22.75	2.92	22.75	0.001*
		(BG)	35.38	5.63	34.55	
	After (TF)	(EP)	30.47	6.22	29.58	0.001*
		(BG)	48.93	8.63	50.96	
	Percent change	(EP)	35.04	27.18	34.01	0.74ns
		(BG)	40.45	30.37	38.36	

Ti, titanium; PEEK, Poly-ether-ether-ketone; TF, thermomechanical fatigue; EP, IPS e.max Press; BG, monolithic ceramic reinforced poly-ether-ether-ketone (BioHPP Granulates).
Significance level P≤0.05, **significant, ns=non-significant*

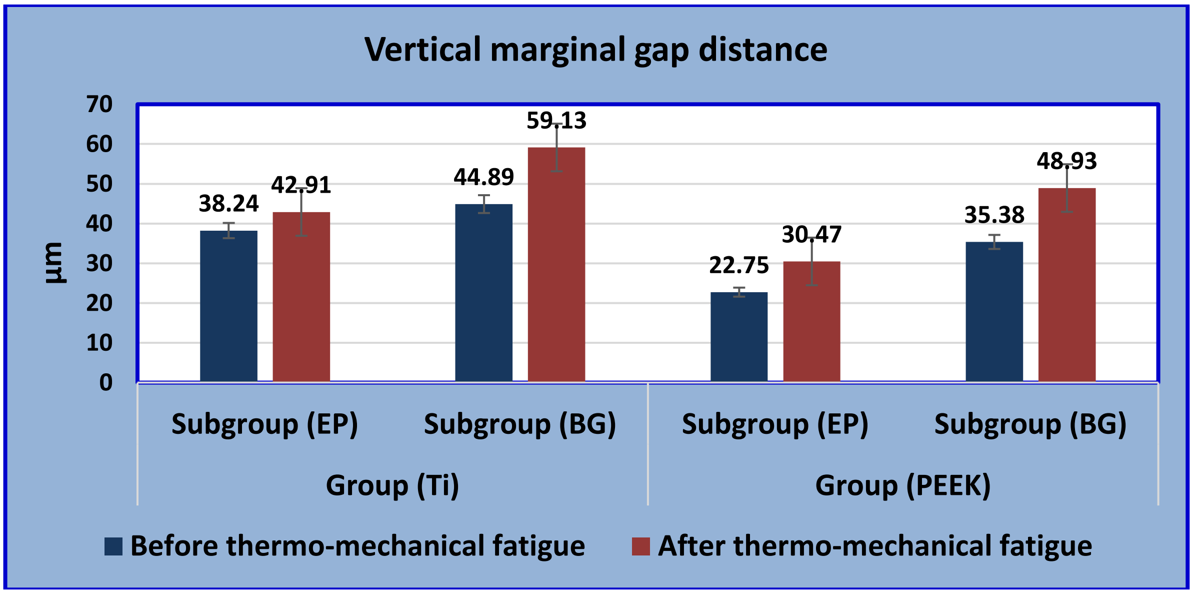

Figure 2: Bar chart illustrating vertical marginal gap distance prior and following the thermo-mechanical fatigue in different subgroups of groups (Ti) and (PEEK).

Ti, titanium; PEEK, Poly-ether-ether-ketone; TF, thermomechanical fatigue; EP, IPS e.max Press; BG, monolithic ceramic reinforced poly-ether-ether-ketone (BioHPP Granulates).

Discussion

Dental implants are a gorgeous decision for substituting missing teeth [13]. Accordingly, increased demand for cosmetic restoration has led to an introduction of non-metallic materials such as PEEK as an alternative to titanium implant abutment [4]. The abutment choices are a chief step to attain cosmetic and functional harmony in implant prostheses [14].

The close match of elastic moduli between PEEK surface and bone results in identical distribution of load, least stress shielding influence and prevention of stress concentration, which makes it a superior material for prosthetic implants [9].

Research states that lithium disilicate-based ceramics are recommended for monolithic superstructures due to their superior esthetics combined with their biocompatibility and good adhesive properties [15].

PEEK is additionally useful as a substitute substance for monolithic crown superstructures because it could resist physiologic occlusal stresses. Moreover, modification of PEEK can deliver superior elasticity up to 18 GPa, this is somewhat similar to the cortical bone (15 GPa) [16]. Unlike brittle ceramic substances, such qualities assist to reduce the occlusal stresses supporting the implant.

Heat pressing is one of the most prevalent fabrication techniques due to its accurate marginal adaptation and lower porosity [17]. The current investigation was undertaken with the aim of evaluating and comparing the marginal adaptation of PEEK granulates with pressable lithium disilicate supported by titanium and PEEK implant abutments.

Because the young's modulus of epoxy resin is comparable to that of jaw spongy bone, a few dummy implants were placed in epoxy resin blocks to mimic the environment of an osteointegrated implant [18]. Titanium and PEEK abutments with (size (Ø 4.3mm, L 9mm)) representing the maxillary second premolar were used in the current investigation like to be used in former investigations [9,10].

The wax patterns in CAD/CAM format were created and machined to improve the fit of pressed restorations by reducing marginal gaps [19]. The lithium disilicate glass ceramic and PEEK have been introduced a monolithic restoration in the dental field to decrease the hazard of delamination related to the classically veneered frameworks, minimizing the manufacturing time and improving cost-effectiveness [20].

Marginal adaptation was evaluated before and after subjecting all samples to thermomechanical fatigue to inspect sample performance. Moreover, thermomechanical fatigue is critical as it affects the long-term viability of the restoration [21].

The absence of union in study designs is a main cause of the differences among various investigations, so marginal gap limit is not standardized [22]. Nevertheless, the majority of researchers still employ the measures developed by [23] during a five-year clinical investigation including one thousand restorations, they determined that the most satisfactory marginal gap was 120 μm. Based on these proposals, the outcomes of the current investigation revealed that all measured marginal gaps, both before and after (TF) were less than 120 μm as shown in (Tables 2,3 and Fig. 2), which fall within the range of clinical acceptance [24].

Regarding implant abutment types utilized for recording the mean vertical marginal gap distance scores regardless of different crown types, as shown in (Table 2 and Fig. 2); the outcomes of the current research displayed that there was a statistically significant variation in marginal gap means scores among both groups. (PEEK) recorded lower marginal gap scores prior and following (TF) compared to (Ti) that agreed with a previous study [25]. It might be related to the fact that implant abutments fabricated from softer materials had smaller gaps than those fabricated from harder materials. This is among the causes why many producers specify a bigger gap in advance when making fixed partial dentures using hard materials (CoCr, Ti, etc.) [26].

For the materials used in the current study, Ti has a hardness that is around 14 times harder than PEEK. This might also be the reason why PEEK and Ti were discovered to have the best fits. Yet, the outcomes of the current research are in dissimilarity with prior research that stated that PEEK restoration is less precise in the margin term in comparison to titanium restoration [27].

Regarding the crown types used on registered vertical marginal gap distance mean values, (EP) subgroup recorded lower marginal gap mean scores prior and following (TF) compared to (BG) subgroup (Table 3 and Fig. 2) that are similar to those of the former study [28]. This could be the excessive variance in elastic moduli among the tested materials that significantly influences the integrity of restoration margins [29].

Rigid materials like IPS e.max transfer less stress to the margins, thus promoting a more stable adhesion. In addition, it might be related to the semi-crystalline composition of PEEK, which comprises fillers incorporated into the resin matrix, thus generating variances in the pressing of both materials [30]. Additionally, the pressing equipment's parameters have a significant impact on the pressing procedure's precision [31].

These findings are in disagreement with a previous investigation stated that the lower the elastic modulus of BioHPP, the superior stress transfer to the implant and the less tensile stresses developed at the adhesive interface. A lower modulus of elasticity allows the crown to deflect to some extent during function without creating stresses that may result in debonding [32].

The marginal gap between the restorations and the implant abutments can rise because of thermal aging [33]. The same outcomes were displayed in the present investigation; the marginal gap scores elevated significantly in all groups following thermomechanical fatigue. Such outcomes may be related to the washing out of some of the luting cement at the margin as a consequence of fluctuations in temperature through aging procedure [34].

Conclusion:

Given the restrictions of the present investigation, it may be concluded that implant abutment types had an effect on marginal gap mean values and for all tested materials, the vertical marginal gap scores documented in the current investigation increased after thermomechanical fatigue. However, they were within the limits of clinically acceptable standards.

List of abbreviation:

(TF) Thermomechanical fatigue.
(Ti) Titanium implant abutments.
(PEEK) Poly-ether-ether-ketone implant abutments.
(EP) Monolithic lithium disilicate "IPS e.max Press".
(BG) Monolithic ceramic reinforced poly-ether-ether-ketone (BioHPP Granulates).

Author contributions

Every author took part in the workshop on consensus. Every author consent to this paper being published.

Funding

No funding

Availability of data and materials

The consensus meeting's protocols are accessible.

Declarations

Ethics approval and consent to participate

The current research was evaluated and consented by the Research Ethical Committee (REC) of the Faculty of Dental Medicine for Girls, AL-Azhar University, under code: (REC-PD-23-05).

Consent for publication
I, the undersigned, hereby consent to the publishing of personally identifiable information in the previously mentioned Journal and Article. This information may include images, videos, case histories, and/or written details ("Material").

Competing interests
No conflict of interest

Acknowledgments
The Dental Research Center at Al-Azhar University's Faculty of Dental Medicine for Girls provided assistance for this study, which the authors gratefully acknowledge.

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