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Marginal Fit and Resistance of Heat Pressed Glass Ceramic Restoration to Fracture with Different Preparation Designs for Occlusal Veneer

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ORIGINAL STUDY

Marginal Fit and Resistance of Heat Pressed Glass-ceramic Restoration to Fracture With Different Preparation Designs for Occlusal Veneer

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Abstract

Purpose: To assess the influence of preparation design on marginal fit and fracture resistance of pressable fabricated occlusal glass-ceramic veneers. **Patients and methods:** Two master preparations, one of the traditional planar design and the other of the modified one, were designed and fabricated by printing on two maxillary first bicuspids. The preparations received an occlusal veneer preparation and a finish line of circumferential-chamfer type. Each prepared design was duplicated 20 times to form 20 epoxy resin replicas ['$n = 20$' dies for conventional planner design (C) group and '$n = 20$' dies for proposed modified design (M) group]. Each group was further subdivided into two subgroups ($n = 10$) based on the material; IPS e.max press (EP) and Vita Ambria press (VA). Stereomicroscope was used to measure the vertical marginal gap distance. Fracture resistance test was conducted using universal testing machine. Data was tabulated and statistics was used to analyze it. Examination and detection of the mode of failure of the fractured samples were also determined. **Results:** IPS e.max press with proposed modified design recorded the least value for the vertical marginal gap distance (60.28 ± 6.95 μm), while VA with conventional planner design recorded the highest mean value of vertical marginal gap distance (98.33 ± 6.77 μm). VA with conventional planner design recorded the highest mean value of failure load (787.96 ± 212.54 N), while VA with proposed modified design recorded the lowest mean value of failure load (644.34 ± 166.67 N). **Conclusion:** Preparation designs and materials marginal gap were within acceptable range. However, neither the design of the preparation nor the material type have affected the resistance of fracture.

Keywords: Fracture resistance, IPS e.max press, Marginal fit, Occlusal veneer, Vita Ambria press

1. Introduction

Conservation of tooth structure is considered to be the main concept and aim of modern dentistry that is greatly required to provide the essential biological fundamentals of teeth preparation [1]. At the moment, this idea has been largely matched by minimally invasive techniques.

Minimal invasive preparation is a promising alternative to conventional preparation procedures. It can preserve up to 40% of tooth structure after preparation [2].

Restoring the loss of the occlusal contact between the upper and lower jaws is considered one of the challenging problems. The etiology could be caries, erosion, abrasion, attrition, abfraction or malposition of the teeth [3]. Severe erosive wear can lead to dentin exposure over time with deterioration of pulpal health and vertical dimension loss. In addition, occlusal restoration thickness could be jeopardized by opposing teeth over eruption as a result of occlusal contact loss [4].

Minimally invasive restorations have been thoroughly investigated since adhesive bonding techniques developed. Occlusal veneers are one sort of least invasive preparation design for severe occlusal wear [5]. Occlusal veneers are defined as: non-retentive, extra-coronal adhesively retained restorations that completely cover the occlusal surface. It is considered to be a conservative alternative to traditional inlays, onlays, and full crowns with promising results. No or minimal preparation is

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required for this type of restorations to the extent that achieves inter-occlusal clearance [6].

Occlusal veneers fabricated from all-ceramics material show satisfactory mechanics, restoring function and esthetic, which preserve tooth structure, pulp vitality, lower hyper sensitivity and easy cementation and long-term reliability [7].

IPS e.max press (EP) is a glass ceramic material that is widely used for various types of indirect restorations because of its high esthetic with good mechanical properties and excellent adhesion to dental tissue [8]. Recently, vita Ambria (VA) pressable zirconia reinforced lithium silicate (ZLS), which combines the mechanical capabilities of zirconia with the translucent property of glass ceramic, was introduced as a result of ongoing developments in monolithic glass ceramics aimed at enhancing their strength properties by providing crack interruption [9].

The marginal adaption of heat-pressed ceramic restorations can be significantly impacted by the fabrication of correct wax patterns. Using computer-aided design/computer-aided manufacturing (CAD/CAM) systems to create wax patterns has various benefits, such as creation of higher-quality patterns, standardization of shaping procedures as well as reduction of manufacturing costs, labor, and time. In addition, they have the potential to improve accuracy because they skip several manufacturing phases that are included in the traditional waxing procedure [10].

Integrity and well fit at dental restorations margins is an essential requirement for durability and good clinical performance of them. The marginal gap represents the vertical distance between the finish line and the most apical part of the restoration [11]. Marginal irregularities may lead to excessive cement at the margins, and microleakage that causes recurrent dental caries, pulpitis, and periodontal health deterioration. Previous research have clinically demonstrated good marginal integrity values between 40 and 120 μm [11,12]. A wider marginal discrepancy up to 200–300 μm has been reported [12].

The inherent brittleness of glass ceramics makes them highly subjected to failure due to fracture, as reported in previous studies, following their clinical use [13,14]. An issue that necessitates the determination of their fracture resistance to be able to assess their durability.

It is documented that preparation geometry affects the marginal fit and fracture resistance and durability of glass ceramic fixed restorations [14]. Minimally invasive design or the 'conventional planar preparation', approach according to the anatomical structure of the occlusal surfaces has been recommended for teeth where a considerable amount of tooth structure has been destroyed by dental caries, erosion, and wear or in the case of vertical dimension augmentation [15]. Therefore, finding a modification to the usual designs aiming to enhance adhesion to various restorative materials, having similar characteristics of occlusal preparation, extending 1 mm on the teeth axial surfaces, and terminating with a circumferential chamfer finish line [16].

The occlusal veneers made from CAD/CAM glass ceramics are well-liked and frequently employed in studies. Although pressable occlusal veneers are a viable alternative to CAD/CAM materials, there is limited research and information available on them. In order to determine how preparation designs affect marginal fit and fracture resistance of occlusal veneers made from two different pressable glass ceramic restorations, the current study will focus on these two factors.

2. Materials and method

2.1. Ethical consideration

This study was approved by the Research Ethics Committee (REC) at the Faculty of Dental Medicine for Girls, Al-Azhar University under Code (REC-CR-23-07).

2.2. Sample size calculation

G power statistical power analysis tool (version 3.1.9.7) was used to determine the sample and it was calculated as a total ($N = 40$) occlusal veneer restoration. This sample size was adequate for a two-sided hypothesis test to detect a big effect size of 0.91 with an actual power (1-error) of 0.8 (80%) and a significance level of 0.05 (5%).

2.3. Construction of 3D printed dies

Two typodont maxillary first premolars with identical dimensions were collected and sprayed with light-reflecting powder (Occlutec, Scanspray, Renfert, USA) and scanned (Ds Mizar, Italy) to make an optical impression of the teeth. Data were transferred to Exocad computer program software (Exocad Software GmbH, Germany) to design standard preparations of occlusal veneers.

The first preparation is minimally invasive preparation 'conventional planner design'. The preparation was standardized with 1 mm occlusal reduction following the anatomy to resemble occlusal erosion [15] (Diagram 1A). The second preparation is 'proposed modified design'. The

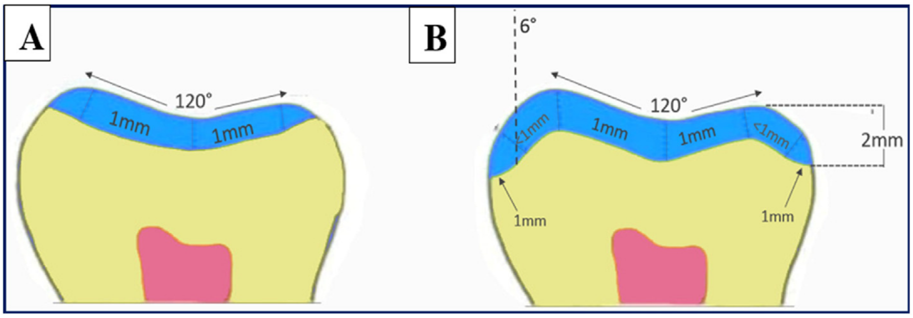

Diagram 1. Occlusal veneer preparation designs; (A) Conventional planner occlusal veneer design. (B) Proposed modified occlusal veneer design.

preparation was standardized with 1 mm occlusal reduction following the anatomy and extended on the axial walls 2 mm apical to the prepared occlusal surface terminating with 1 mm circumferential chamfer finish line. The convergence angle was 6° and the angle between buccal and palatal cusps was 120° [16] (Diagram 1B). The designs were saved as standard tessellation language file. A standard tessellation language file was transferred to a three dimensional (3D) printer machine (ANYCUBIC Photon Mono SE, China) to print the resin dies.

2.4. Construction of epoxy resin blocks

Each prepared 3D printed resin die was embedded in the center of plastic cylinder (1.6 cm height and 1.5 cm diameter) filled with epoxy resin leaving 2 mm below the cervical line and left for complete polymerization of epoxy resin finally finished and smoothed.

2.5. Duplication of the prepared 3D printed resin teeth

Silicon mold for the prepared 3D printed teeth was made using duplicating addition silicon material (Replisil 22, Dent-e-con, Germany). Each prepared design was duplicated to form 20 epoxy resin replicas (20 dies for the conventional planner design and 20 dies for proposed modified design). Then epoxy resin material (EgyPro epoxy resin, EgyPoxy, Egypt) was mixed and poured into the silicon mold and left until full hardness. After full hardness, the epoxy resin dies were separated from the silicon mold.

2.6. Samples' grouping

A total of forty epoxy dies samples were used in the present study. Epoxy dies were divided into two groups; Group (C): 20 epoxy dies with minimally invasive preparation 'conventional planner design'. Group (M): 20 epoxy dies with circumferential chamfer finish line 'proposed modified design'.

Each group was further subdivided into two subgroups (10 occlusal veneers each) according to the pressable glass ceramic material used for the fabrication of occlusal veneers: Subgroup (EP): 10 occlusal veneers fabricated from EP glass-ceramic materials. Subgroup (VA): 10 occlusal veneers fabricated from VA glass ceramic materials.

2.7. Occlusal veneer fabrication

Occlusal veneers were fabricated using the heat pressing technique; CAD/CAM milled wax templates were created to standardize the thickness and design of manufactured pressable glass ceramic occlusal veneers across both groups and subgroups. The milling process of wax patterns was accomplished using Roland machine which is 5-axis dental milling machine (Roland DG Corporation, Hamamatsu, Japan). Then all wax patterns in both groups were sprued, invested, preheated and burned out forming a mold ready for pressing. EP ingots (Ivoclar Vivadent, Schaan, Liechtenstein, Germany) were pressed in the pressing furnace (Programat EP3010; Ivoclar Vivadent, Germany) to produce IPS e-max occlusal veneers. While VA ingots (VITA Zahnfabrik, Germany) were pressed in the pressing furnace (Vita Vacumat 6000 MP, Vita Zahnfabrik, Rauter GmbH and Co. KG, Germany).

After that, divesting, finishing and polishing were performed for each sample of occlusal veneers according to manufacturer's instructions. Each occlusal veneer was seated on its corresponding die and checked for seating and any flaws. Finally, all occlusal veneers were adhesively cemented using SuperCem self-adhesive resin cement (DentKist, Korea) under axial 5 Kg load [17] during the curing process (Fig. 1A–I).

2.8. Testing procedures

2.8.1. Marginal fit determination

Marginal fit was evaluated in term of measuring the vertical marginal gap distance using digital stereomicroscope (MA 100 Nikon stereomicroscope, Japan). The dies were measured at 12 points, three points at each surface, with fixed distance between points '2 mm' in mesial and distal surfaces and '1 mm' in buccal and palatal surfaces. Margins were photographed at a fixed magnification of 50×. A digital image analysis system (OmniMet image analysis software) was used to measure and evaluate the gap width.

2.8.2. Fracture resistance

Fracture resistance was determined by recording sample failure under compressive load. Epoxy resin dies were attached to the lower fixed head of the universal testing machine (Instron model 3345, Norwood, USA) and subjected to continuous static load (5 KN) using a stainless-steel ball 4 mm diameter attached to the upper movable head of the testing machine. Axial compression force was applied to the center of the occlusal surface at a crosshead speed of 1.0 mm/min until specimen failure.

Fracture mode analysis was performed using a magnifying lens (10×) (Optics Co, Beijing, China) to classify the fracture mode according to Burk's classification [18]:

Code 1: Minimal fracture or crack in occlusal veneer.
Code 2: Less than half of occlusal veneer lost.
Code 3: Occlusal veneer fracture through midline (half of the veneer is displaced or lost).
Code 4: More than half of the occlusal veneer is lost.
Code 5: Sever fracture of epoxy resin die and/or occlusal veneer.

2.9. Statistical analysis

Statistical analysis was performed using SPSS version 20 (Armonk, NY: IBM Corp). Numerical data were summarized using mean, standard deviation, confidence intervals and range. Comparisons between groups were performed by analysis of variance test. All *P* values are two-sided. *P* values less than or equal to 0.05 were considered significant.

3. Results

3.1. Marginal fit: (vertical marginal gap distance 'μm')

Proposed modified design (group M) recorded statistically significant lower mean vertical marginal gap distance compared with conventional planner design (group C) ($P = 0.001$). In both groups; IPS e.max press, subgroup (EP) recorded statistically significant lower mean vertical marginal gap distance compared with VA subgroup ($P = 0.00$).

Comparing all subgroups together; EP with proposed modified design, subgroup (M-EP) recorded the statistically significantly lowest mean vertical marginal gap distance, while VA with conventional planner design, subgroup (C-VA) recorded the statistically significantly highest mean value of vertical marginal gap distance. However, marginal gaps of all subgroups were within clinically accepted ranges (Table 1, Fig. 2).

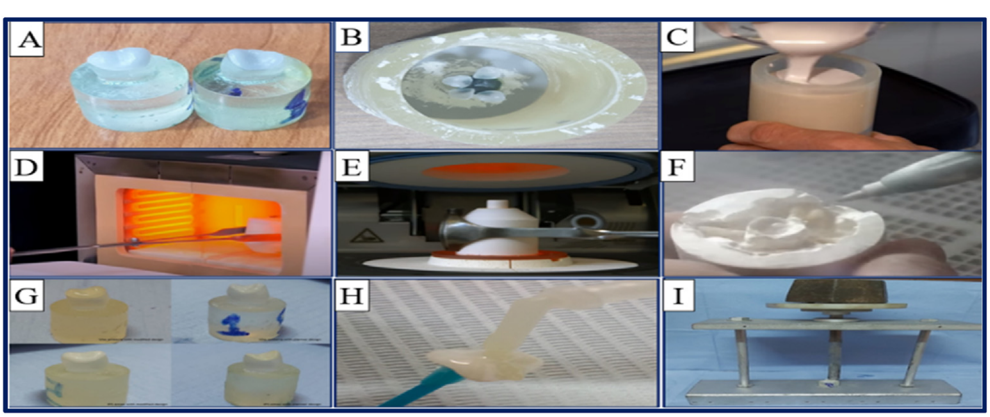

Fig. 1. (A) Milled wax patterns seated on its corresponding die. (B) Spruing wax patterns inside rubber casting ring. (C) Investing. (D) Preheating process. (E) Pressing process. (F) Rough divesting with polishing jet. (G) Occlusal veneers seated on its corresponding die. (H) Application of supercem resin cement. (I) Cementation of occlusal veneer under holding device.

3.2. Fracture resistance (failure load 'N')

Conventional planner design, group (C) recorded statistically non-significant higher mean value compared with proposed modified design, group (M) ($P = 0.751$). Subgroup EP recorded a nonsignificant higher mean failure load compared with VA, subgroup (VA) ($P = 0.908$).

Comparing all subgroups together, VA with conventional planner design, subgroup (C-VA) recorded the statically nonsignificant highest mean failure load, while VA with proposed modified design, subgroup (M-VA) recorded the statically nonsignificant lowest mean value of failure load (Table 2, Fig. 3).

3.3. Mode of failure analysis

It was observed that the most common failure mode occurred in conventional planner design, group (C) was sever fracture of epoxy resin die or occlusal veneer (Code 5), followed by occlusal veneer fracture through midline (Code 3). In the proposed modified design, group (M); severe fracture of epoxy resin die or occlusal veneer (Code 5) was the predominant failure mode, followed by fracture of more than half of the occlusal veneers (Code 4).

4. Discussion

Recent restorative dental technology aims to preserve tooth structure. Minimal invasive dentistry

Table 1. Mean values, standard deviation (SD) and statistical analysis of vertical marginal gap distance (μm) and comparison of different preparation designs and materials (analysis of variance test).

Subgroups	Mean ± SD (μm)	95% confidence interval for mean (μm)		Min	Max	F value	P value
		Lower bound	Upper bound				
IPS e. max press (C-EP)	77.13 ± 10.24	69.81	84.45	62.12	84.94	32.48	0.000[a]
IPS e. max press (M-EP)	60.28 ± 6.95	55.31	65.25	49.60	68.37		
Vita Ambria (C-VA)	98.33 ± 6.77	93.48	103.17	92.63	110.52		
Vita Ambria (M-VA)	92.38 ± 12.57	83.38	101.37	77.24	109.83		

Significance level P less than or equal to 0.05.
[a] Significant.

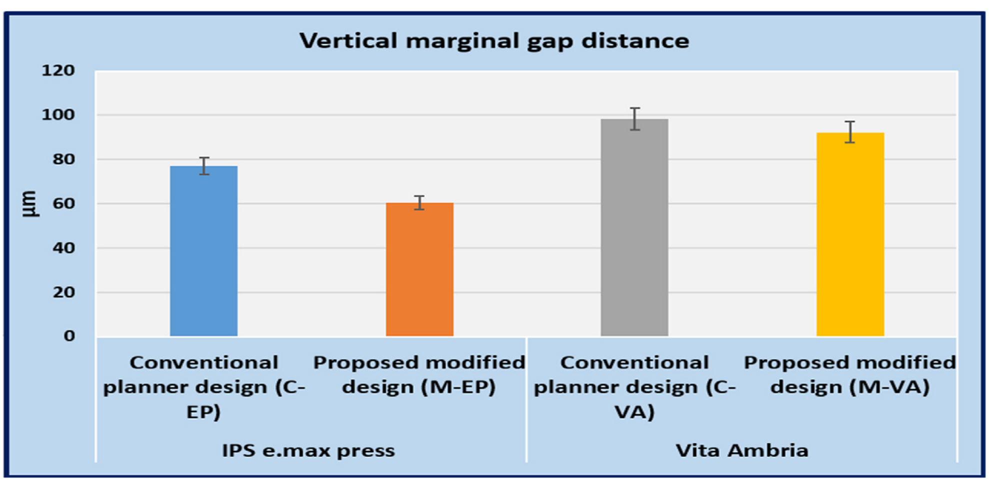

Fig. 2. Bar chart illustrating vertical marginal gap distance (μm) in different subgroups.

Table 2. Mean values, standard deviation (SD), and statistical analysis of failure load (N) and comparison of different preparation designs and materials (analysis of variance test).

Subgroups	Mean ± SD (N)	95% confidence interval for mean(N)		M	Max	F value	P value
		Lower bound	Upper bound				
IPS e.max press (C-EP)	688.08 ± 311.06	301.85	1074.31	401.35	1101.38	0.44	0.73 ns
Vita Ambria (C-VA)	787.96 ± 212.54	524.05	1051.86	546.50	967.35		
IPS e.max press (M-EP)	767.54 ± 191.30	530.00	1005.07	527.02	959.39		
Vita Ambria (M-VA)	644.34 ± 166.67	437.39	851.29	445.21	899.21		

Significance level P less than or equal to 0.05, ns = nonsignificant.

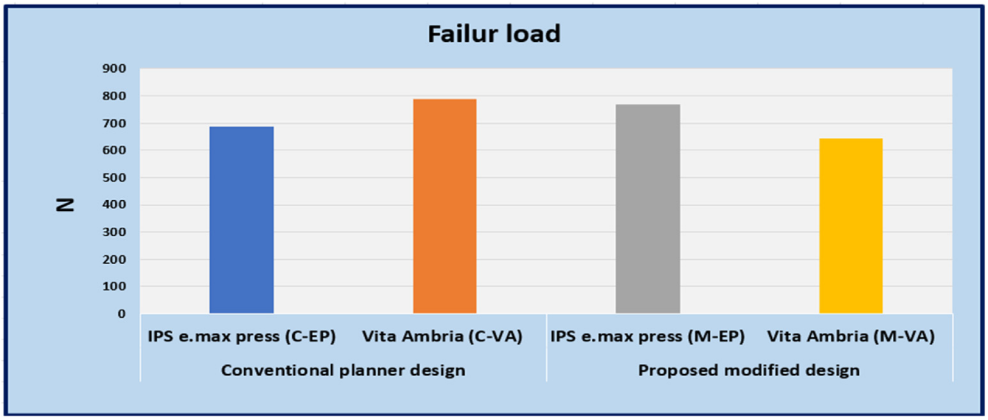

Fig. 3. Bar chart illustrating failure load (N) in different subgroups.

can help to maintain the balance between esthetic, mechanical, and biological principles. Occlusal veneers are regarded as a desirable prosthetic substitute to traditional full coverage as well as onlays that fulfill these criteria of minimally invasive approach to rehabilitate occlusal problems [1,19].

Selecting the appropriate type of dental restorative material that has its advised dimensions, thickness, and bond-durability, is essential for the success of such restorations. All of the aforementioned elements can provide superior strength and resistance for dental tissues and restorations simultaneously [20]. Glass ceramic restorations were chosen in the current investigation as a restorative material due to its qualities which meet the needs of such treatment prosthetic options.

Application of extraneous pressure at high temperatures during sintering of the viscous glass ceramics was found to be essential in order to have a glass ceramic restoration with superior flexural strength, accurate marginal integrity and reduced porosity [21]. According to several studies, heat pressing technology, as opposed to CAD/CAM approach, provided greater fracture resistance for lithium disilicate glass ceramic restorations [22,23].

Heat pressing technology in conjunction with using lithium silicate glass ceramics that is zirconia-reinforced was postulated lately to create a very attractive all-ceramic dental restoration. This substance was created using the primary crystalline phase of lithium silicate, that exists in a glassy translucent matrix and reinforced through addition of zirconium dioxide crystalline structures. The keys for enhanced characteristics of this material are its good mechanical qualities and opalescent transparency properties [24].

Both materials combine minimally invasive biomimetic concepts with strong qualities. Therefore, it was important to test making posterior occlusal veneer restorations using these materials with different preparation designs in the hopes that this will create the groundwork for a successful marginal fit and fracture resistance for these kinds of restoration.

To standardize the different preparation designs, they were designed and 3D printed using 3D printing machine (ANYCUBIC Photon Mono SE, China). The preparation designs chosen in the current methodology followed the instructions of minimal invasive dental restorations demonstrated by preceding studies [15,16,25]. They were duplicated to obtain 20 epoxy resin dies for each preparation. Being similar in elasticity to dentin (12.9 GPa modulus of elasticity), epoxy resin dies have been used as a proposed substitute for natural teeth, since it has been demonstrated that the resistance to fracture of all ceramic restorations greatly rely upon the modulus of elasticity of the abutment [26].

To standardize the step of wax pattern construction during heat pressing technique; wax patterns were designed using CAD/CAM software which makes this step simple, fast, and accurate. CAD wax is characterized by high torsional stiffness, dimensional accuracy and burning out with no residual resulting in an excellent fit of the final restorations [27].

In the current study, the results suggested that the preparation designs and the kind of materials significantly increased the values of mean marginal gap distance. However, none significantly affected the value of fracture resistance.

Microleakage, cement dissolution, and carious lesions are all consequences of inadequate marginal fit between restorations and teeth which also affect the restoration's longevity. Marginal gap in the current study was evaluated through using a stereomicroscope (MA 100 Nikon) as it is considered a non-destructive investigation tool [28]. The measurements of vertical marginal gap of occlusal veneers of all subgroups in the current study were within clinical accepted range as several researchers agreed that the acceptable range is 40–120 μ [11,12] (Table 1, Fig. 2).

The outcomes of vertical marginal gap measurement of occlusal veneers with two preparation designs showed that the proposed modified design recorded lower statistically significant difference compared with conventional planner design which was very clear in EP subgroup (Table 1, Fig. 2). This was by previous studies which found that the modified preparation designs showed better results than conventional design. It may be suggested that preparation with a finish line provides enhanced resistance than undefined finish line found in the conventional preparation designs which offer reduced marginal gap, enhanced internal support, and wide area available for bonding [15,29].

On the contrary, it was proved that the marginal integrity of veneers comprising anatomical occlusal preparation revealed minimal marginal gap in comparison with finish line preparation and explained that because of shifting to more complicated geometry, marginal gap size is increased [30].

A comparison between the results of vertical marginal gap of both investigated glass-ceramics showed that EP had a statistically significant lower marginal gap mean value than VA in both preparation designs (Table 1, Fig. 2). This was in agreement with study stated that lithium disilicate processed by CAD wax technique recorded lower marginal gap value than ZLS restoration handled by CAD wax. This could be attributed to zirconia incorporation into the glassy matrix of lithium disilicate resulted in poor margin adaptation. The high ZrO_2 content in ZLS improved the viscosity of the material as well as its reduced flow, jeopardizing the marginal integrity of occlusal veneers [21].

Another study showed disagreement and reported that ZLS had statistically significant lower marginal gap compared with that of lithium disilicate before thermocycling [31]. This could be because ZLS has smaller crystals than lithium disilicate, which makes the material more compressible and flowable resulting in improved marginal fit [32].

Dental glass-ceramics are inherently brittle but have excellent resistance to compressive loads, so it is necessary to test their fracture resistance as it is considered the most significant determinant for all ceramic dental restoration durability [13]. The test was performed through the application of stationary loads till fracture by a universal material-testing machine [33].

The results of fracture resistance of occlusal veneers regarding the effect of the two preparation designs and two tested glass-ceramic materials show that there was a statistically nonsignificant difference between them (Table 2, Fig. 3).

With regards to the design of preparation for restoration; the conventional planner design showed a higher mean failure load than the proposed modified design (Table 2, Fig. 3). This was in harmony with former research reported that anatomical occlusal veneers revealed more enhanced resistance to fracture than veneers with occlusal and lingual surface coverage. This could be explained based on that more invasive preparation of the axial walls can lead to higher tensile stresses within the ceramic restoration. Therefore, increasing the number of axial walls restored reduces the fracture resistance and increases the maximum core stress in the restoration [34].

The current results disagree with a study which revealed that modification of the design of occlusal veneers provided superior fracture resistance than conventional designs. This was owed to equal distribution of stresses overt the offending abutment provided by the circumferential finish line design [35].

With regards to the materials, EP recorded a statistically nonsignificant higher mean failure load than VA (Table 2, Fig. 3). These findings were in concurrence with recent research which revealed no significant differences between preparation designs regardless of the material used. Also found that lithium disilicate restoration showed a statistically non-significant higher mean value than ZLS restoration. The incorporation of zirconia inside the glassy vitreous matrix of lithium disilicate did not promote fracture strength. More than 10% ZrO_2 content in ZLS press causes ceramic to be processed at lesser temperature degrees which in turn results in a partial and uncompleted crystallization. This resulted in decrease in crystal growth and low fracture resistance [36].

Catastrophic failure which included severe fracturing of occlusal veneers and epoxy resin dies was the most frequent failure pattern in both groups. This is in accordance to previous studies reported that failure involving both ceramics and tooth with occlusal veneers bonded to dentin as the main failure mode and suggesting that these restorations are as strong as the worn teeth they are supposed to restore. Additionally, the efficient bonding between die and glass ceramics enables the force to transmit through the restoration-die complex [22,37].

The current study has some limitation: the usage of epoxy dies as an alternative to natural teeth does not stimulate the clinical condition. In addition, the absence of the thermomechanical loading is an important step of the aging procedure. Both can have a negative impact on the examined attributes. Moreover, the horizontal gap was not examined and the vertical marginal gap distance was only recorded at the present investigation.

4.1. Conclusion

Under the limitations of the present study, it can be concluded that:

(a) Marginal gap of preparation designs and materials did not exceed what was mentioned in the previous studies as acceptable range.
(b) IEP with proposed modified design posterior occlusal veneers has a superior marginal fit.
(c) Both preparation designs and tested restorative materials revealed good resistance to fracture that was superior to the advised minimal fracture strengths for dental restorations at the posterior region.
(d) There was no effect of the preparation designs or the material types on the fracture resistance of occlusal veneers.

4.2. Recommendations

It is recommended that future research should include natural teeth and thermomechanical loads to better imitate the oral environment. Clinical studies are recommended to validate the reliability of using both preparation designs and glass-ceramic materials.

Ethics approval

This study was approved by the Research Ethics Committee (REC) at the Faculty of Dental Medicine for Girls, Al-Azhar University under Code (RECCR-23-07).

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Conflicts of interest

There are no conflicts of interest.

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