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Fracture Resistance, Marginal Gap and Internal Gap of Lithium Disilicate Occlusal Veneers with Two Preparation Designs

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A B S T R A C T

Objectives: Lithium disilicate is commonly used for restoring worn teeth. Various preparation designs have been introduced for occlusal overlay restorations, potentially impacting the properties of the restoration. This study evaluated the fracture resistance, marginal gap, and internal gap of lithium disilicate occlusal veneers prepared with two different preparation designs.

Materials and Methods: In this in vitro study, 22 extracted mandibular molars were randomly assigned to two groups (n=11). In the non-retentive (NR) preparation group, the occlusal surface was reduced by 0.8mm in the fissures and 1mm at the cusp tips. In the retentive (R) group, in addition to occlusal reduction, the axial surfaces were reduced with a round-end shoulder finish line created around the axial wall, with both height and depth measuring 1mm. Occlusal veneers were fabricated using lithium disilicate (IPS e.max Press). The marginal and internal gaps were measured using the silicone replica technique before cementation. After cementation, the restorations underwent thermocycling and load cycling, followed by fracture resistance testing in a universal testing machine. Data were analyzed by independent t-test.

Results: The fracture resistance of the R group was insignificantly higher than that of the NR group (P=0.310). The marginal gap (P=0.001) and internal gap (P=0.021) of the R veneers were significantly larger than those of the NR veneers.

Conclusion: Both R and NR occlusal veneers exhibited sufficient strength for posterior tooth restorations. The marginal and internal gaps of R and NR occlusal veneers fabricated from lithium disilicate (IPS e.max Press) were found to be within the acceptable range.

Keywords: Dental Marginal Adaptation; Dental Veneers; Flexural Strength; Lithia Disilicate

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INTRODUCTION

Over time, the occlusal enamel may be subjected to wear or severe erosion, resulting in reduced enamel thickness and potential exposure of the underlying dentin at the occlusal surface. Consequently, pulp involvement, impaired occlusion, and compromised esthetics and function may be encountered. In such situations, a conservative prosthetic alternative to traditional full-coverage crowns can be provided by bonded posterior occlusal veneers [1-3].

Preservation of tooth structure is regarded as a significant driving force in restorative dentistry. Occlusal veneers' advantage lies in their ability to restore function and esthetics while conserving a significant amount of dental structure. Minimally invasive approaches can preserve up to 40% of the tooth structure [4].

Occlusal veneers are supragingival bonded restorations that offer several advantages, such as elimination of the need for traumatic subgingival margin placement techniques, easier seating and cementation of the restoration without risk of contamination and periodontal inflammation, no requirement for retention or resistance forms, and simplified impression-taking, particularly optical impressions [5]. Two basic categories have been identified for tooth preparation for occlusal veneers: non-retentive (NR; planar) and retentive (R) occlusal surface preparations [6,7]. In NR preparation, only the occlusal surface is prepared, with the original cuspal inclination being maintained as much as possible. The amount of occlusal reduction is determined by the restorative material used, typically ranging from 0.5 to 1mm in the central fissure and 0.5 to 1.2mm along the cuspal slopes [8]. This preparation design was introduced to minimize tooth structure loss and reduce the risk of dentin exposure [9].

In R occlusal veneer preparation, the occlusal surface is reduced by 1mm and a circumferential shoulder with a rounded inner edge or chamfer is created at an angle of approximately 10–30 degrees. The width of the shoulder or chamfer must be at least 1.0mm [10].

Occlusal veneers have been fabricated using various materials, including feldspathic ceramics, high-translucency zirconia, zirconia-reinforced lithium silicate, composite resin, polymer-infiltrated ceramics, polymethylmethacrylate, resin nano ceramics, and lithium disilicate glass-ceramics [11-13]. Excellent properties such as biocompatibility, good translucency, dimensional stability, and mechanical strength are offered by lithium disilicate glass ceramics. Various features of occlusal veneers made from IPS e.max CAD have been examined in previous studies [14-16]. However, little attention has been directed to IPS e.max Press in the literature. Higher fracture toughness is exhibited by IPS e.max Press lithium disilicate compared to IPS e.max CAD in crowns [17] and significantly smaller marginal gaps in vitro [18]. It is regularly used for slightly invasive restoration of teeth that have lost their shape. The pressable type (IPS e.max Press) can be treated in monolithic form and has been supported for the restoration of worn teeth. In clinical practice, posterior restorations demonstrate high survival rates, with lithium disilicate ceramic restorations showing persistence rates between 95% and 100%. Furthermore, monolithic restorations exhibit fewer structural complications compared to layered restorations [18].

The accurate fit of restoration is considered critical for its long-term success, and is determined by both marginal and internal gaps. A minimal marginal gap is known to help reduce gingival irritation, cement dissolution, recurrent caries, and marginal discoloration. An ideal internal fit is recognized to enhance the mechanical performance of all ceramic restorations in terms of strength, resistance, and retention. Although some controversy remains regarding the clinically acceptable standard of marginal fit, it is generally agreed by most authors that marginal discrepancy should be less than 120µm [19].

This in vitro study aimed to assess the fracture resistance, marginal gap, and internal gap of occlusal veneers with two different preparation designs. The null hypothesis of the study was that the two preparation designs would have no significant difference in the abovementioned parameters.

MATERIALS AND METHODS

To calculate the sample size, a two-sample t-test power analysis was conducted using PASS 11 software and analysis of variance, based on the comparison of preparation designs between two study groups under thermocycling and cyclic loading conditions. Assuming standard deviations (S1=72.5, S2=149.3), the minimum required sample size for the fracture resistance test and thermocycling was determined to be 11 specimens per group.

Twenty-two intact, unrestored human mandibular molars (ethical approval code: IR.TUMS.DENTISTRY.REC.1398.186), matched for size, were collected and stored in 0.1% thymol solution (Caelo, Hilden, Germany) at room temperature for 14 days [20,21].

Specimen preparation:

The teeth were meticulously cleaned using periodontal currettes (HU-Friedy Immunity, Chicago, IL, USA) and subsequently stored in 0.9% sodium chloride solution (Iranian Parenteral and Pharmaceutical Co., Iran) at 4 °C until the experiment. To ensure uniformity in tooth dimensions, measurements were made using a digital caliper (Mitutoyo Corporation, Japan), and any specimens that did not conform to the following criteria were excluded: crown mesiodistal width of 9±1.0mm, buccolingual width of 8±1.0mm, crown height of 7±1.0mm, and overall length of 20.0±1.0mm. To simulate the periodontal ligament, one layer of polyether impression material (Impregum Soft; 3M ESPE, St. Paul, MN, USA) was applied on the root surface 2mm apical to the cementoenamel junction with a uniform thickness of 0.25mm. The teeth were subsequently embedded vertically in custom-made plastic molds (15mm in diameter) using auto-polymerizing polyester resin (Technovit 4000; Heraeus Kulzer), with the resin positioned 2mm apical to the cementoenamel junction. Based on the preparation design, the specimens were randomly divided into two groups (n=11):

NR group: The occlusal surface was reduced by 0.8mm at the central fissures and 1mm at the cusp tips (Fig. 1).

R group: Occlusal reduction was carried out in the same manner as in the NR group (Fig. 2).

Fig 1. Non-retentive group: Occlusal surfaces were reduced by 0.8mm at the fissures and 1mm at the cusp tips

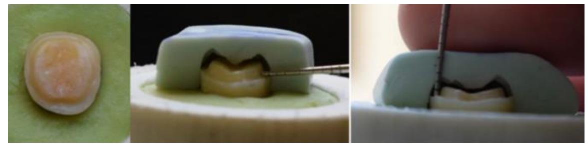

Fig 2. Retentive group: Preparation with round-end shoulder finish line with 1mm depth and 1mm height

Additionally, a round-end shoulder finish line was created around the axial wall, with both height and depth measuring 1mm and a total occlusal convergence angle of 12 degrees. Prior to the preparation of each tooth, a silicone index was fabricated using heavy-body condensation silicone (Speedex; Coltène Whaledent AG, Germany) to assess the amount of occlusal reduction. All preparations were executed manually by one single operator using a high-speed handpiece (Teezkavan, Tehran, Iran) fitted with a diamond bur (D+Z; 856f; Diamante GmbH, Switzerland) under constant water irrigation. All cavity preparations were confined to the enamel.

Restoration fabrication:

The prepared teeth were digitized using a 3Shape Trios-3 intraoral scanner (Standard-P12; 3Shape A/S). The digital impressions were converted to STL files and transmitted to a dental laboratory. The restorations were virtually designed using CAD/CAM software (3Shape Dental Designer Premium 2013; 3Shape, Copenhagen, Denmark). The CAD/CAM wax pattern technique was employed in this study to fabricate the restorations. Previous research has indicated that the traditional wax pattern technique produces larger marginal gaps compared to the CAD/CAM technique.

All restorations were digitally created by the same operator, and a semi-anatomical form was used by the software to maintain uniform ceramic thickness. Restoration thickness was standardized across all groups: 1mm at the cuspal region and 0.8mm in the fissure region. In the R group, an additional 1mm in height and depth was incorporated into the axial shoulder margins.

For the lost-wax pressing procedure, the finalized digital designs were milled from wax blanks (AP White Lemon Wax Blank, AESTHETIC-PRESS WAX Blanks; Düsseldorf, Germany) using a milling unit (Zenotec Mini; Wieland Dental, Pforzheim, Germany). The restorations were subsequently fabricated using lithium disilicate glass-ceramic ingots (IPS e.max Press; Ivoclar Vivadent, Schaan, Liechtenstein) by a certified dental technician, following the guidelines provided by the manufacturer.

The internal surfaces of the restorations were inspected under a stereomicroscope (Model SMZ 1500; Nikon Corp., Tokyo, Japan) at 10× magnification. Any residual irregularities from the investment process were eliminated using a diamond rotary instrument (Brasseler, Savannah, GA, USA). No further modifications were made to the intaglio surfaces. The veneers were seated onto the prepared teeth with an adhesive handling device (OptraStick; Ivoclar Vivadent), and the precision of fit, along with marginal adaptation, was evaluated. The thickness of the restorations was also assessed and adjusted when necessary.

Following the trial fitting, the restorations were stabilized using IPS Object Fix putty (Ivoclar Vivadent; Schaan, Liechtenstein) on a firing tray. A glaze paste (e.max CAD Glaze Paste; Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the occlusal surface. The veneers were subsequently crystallized in a furnace (Programat EP 5000; Ivoclar Vivadent, Schaan, Liechtenstein) using the CAD Crystal/Glaze program at 850 °C, according to the manufacturer's instructions.

Marginal and internal gap evaluation:

The silicone replica technique was employed to evaluate the marginal and internal gaps. Light-body condensation silicone (Speedex; Coltène Whaledent AG Altstatten, Switzerland) was applied to the internal surfaces of the veneers, which were subsequently positioned onto their corresponding teeth and maintained under an apically applied load of 50 N until the impression material was completely polymerized. Any excess material was cautiously excised using a surgical scalpel.

The silicone replica was divided into eight equivalent parts: one mesiodistal section and three buccolingual sections. Marginal and internal gap measurements were made under an optical stereomicroscope (Model SMZ 1500; Nikon Corp.Tokyo, Japan) at 1.6×2 enlargement, with the veneers seated on their respective teeth.

For the R veneers, measurements were made at 8 points along the margin and 40 points on the internal surface (Fig. 3). For the NR veneers, 8 points were measured along the margin and 24 points on the internal surface of each coping (Fig. 4).

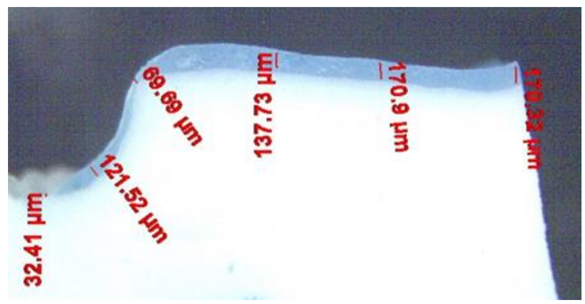

Fig 3. Silicon replica pattern of a retentive veneer under a stereomicroscope (Model SMZ 1500; Nikon Corp.Tokyo, Japan) at 1.6×2 enlargement

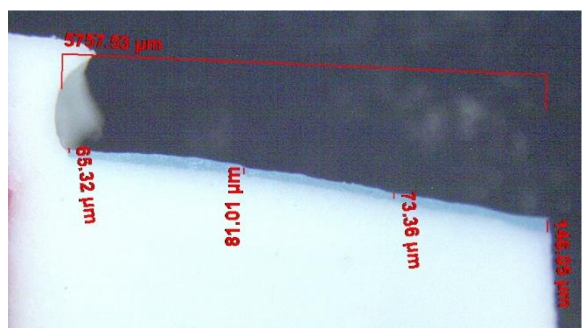

Fig 4. Silicon replica pattern of a non-retentive veneer under a stereomicroscope (Model SMZ 1500; Nikon Corp.Tokyo, Japan) at 1.6×2 enlargement

Veneer cementation:

The occlusal veneers were cleaned in distilled water in an ultrasonic bath (Eurosonic 4D, Euronda, Vicenza, Italy) for a duration of 3 minutes. Subsequently, 9% hydrofluoric acid etching gel (IPS Ceramic Etching Gel, Ivoclar Vivadent) was applied on the intaglio surface of the veneers for 20 seconds, followed by thorough rinsing with a water spray for an additional 20 seconds. Equal volumes of silane components A and B (S, Bis-Silane, Bisco Inc, Schaumburg, USA) were then applied in two successive layers onto the etched internal surface. Each prepared tooth was conditioned with 37% phosphoric acid (Total Etch, Ivoclar Vivadent) for 30 seconds. The etching agent was entirely removed by rinsing with water spray for 20 seconds, after which the teeth were dried using oil-free compressed air. Thereafter, equivalent quantities of ED Primer II A/B (Panavia F 2.0, Kuraray Noritake Dental Inc, Tokyo, Japan) were dispensed onto the prepared surfaces and allowed to remain for 30 seconds. A gentle stream of air was used to volatilize the solvents until a glossy appearance was observed on the primed surfaces. Next, equal portions of the resin cement paste A/B (Panavia F 2.0, Kuraray Noritake Dental Inc, Tokyo, Japan) were thoroughly blended for 20 seconds and subsequently applied on the internal surface of the veneers. The restorations were then seated onto the corresponding preparations and initially light-cured for 2-3 seconds using LED curing device (Bre.Lux Power Unit, bredent GmbH & Co. KG, Senden, Germany). An air-blocking gel (Oxyguard II; Kuraray, Tokyo, Japan) was applied along the margins of the cemented restorations to prevent the formation of an oxygen-inhibited resin layer. Final polymerization was accomplished using a light-curing device (Elipar 2500; 3M ESPE, St. Paul, MN, USA) for 20 seconds from the occlusal, mesial, distal, buccal, and lingual aspects at a distance of 5mm. To ensure complete auto-polymerization of the luting agent, the restored specimens were immersed in distilled water at 37 °C for 14 days [2].

Loading tests:

All specimens from each experimental group were subjected to thermocycling (TC-300; Vafaei Industrial, Tehran, Iran) within a temperature range of 5°C to 55°C, with a dwell time of 30 seconds at each temperature. A total of 5,000 thermal cycles were completed to simulate intraoral temperature fluctuations and moisture conditions.

For mechanical fatigue testing, tripod contact between a 6-mm diameter steel cylinder and the occlusal surface was verified using articulation paper (Fig. 5). The specimens were then exposed to cyclic loading (TC-300; Vafaei Industrial, Tehran, Iran), with 600,000 cycles applied at 10kg and 2Hz. The steel cylinder was positioned on the occlusal surface throughout the procedure. Each specimen was thoroughly examined for the presence of microcracks or fractures.

Fig 5. Checking tripod contact with articulation paper

The surviving specimens were wrapped in 0.5mm tin foil and subjected to increasing vertical loads until fracture occurred. The compressive force was applied at a crosshead speed of 2mm/min using a rounded stainless-steel tip with an 8mm diameter, simulating contact with opposing teeth.

Fracture mode :

All specimens were visually inspected following load testing in the universal testing machine, and representative images were captured using a Nikon D7500 digital camera (Nikon, Tokyo, Japan). The failure modes were classified as follows (Fig. 6):

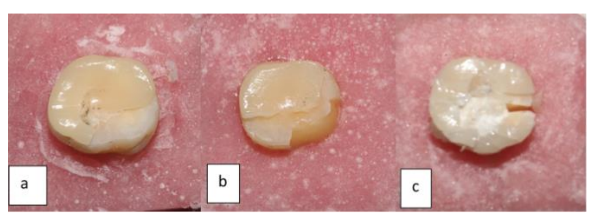

Fig 6. (a) failure type I, (b) failure type II and (c) failure type III

Type I: Fracture confined to the restoration only
Type II: Fracture involving both the restoration and enamel
Type III: Fracture encompassing the restoration, enamel, and dentin

Statistical analysis:

Statistical analysis was performed using IBM SPSS Statistics for Windows, version 20.0 (IBM Corp., Armonk, NY, USA). The independent t-test was employed to compare the differences in fracture resistance, marginal gap, and internal gap between the two preparation design groups. A significance level of 0.05 was established for all statistical tests.

RESULTS

The values for the marginal and internal gap, and fracture resistance for both preparation design groups are presented in Tables 1 and 2, respectively.

Statistically significant differences were observed between the two groups in both the marginal and internal gaps, and independent t-test indicated significantly larger marginal (P=0.001) and internal (P=0.021) gaps for the R veneers when compared to the NR occlusal veneers.

One specimen from the NR group fractured between 500,000 and 600,000 cycles, while all other specimens remained intact after undergoing 600,000 cycles.

The mean fracture resistance of the R occlusal veneers was slightly higher than that of NR occlusal veneers. However, this difference was not statistically significant (P=0.310).

Table 3 presents the distribution of failure modes.

DISCUSSION

Two different occlusal veneer preparation designs were compared for marginal and internal gap and fracture resistance. The results revealed that R occlusal veneers exhibited insignificantly higher fracture resistance than NR occlusal veneers.

Table 1. Comparison of the two groups regarding marginal and internal gap (μm) by t-test

Group	Gap	Mean	SD	Mean difference	P value	95% CI	
						Lower bound	Upper bound
Retentive	Marginal	68.52	11.98	-19.18	0.001	-29.24	-9.12
Non-retentive	Marginal	49.33	10.56				
Retentive	Internal	141.85	14.30	-13.06	0.021	-23.97	-2.15
Non-retentive	Internal	128.78	9.81				

SD: Standard deviation

Table 2. Mean and standard deviation values of fracture resistance for retentive and non-retentive occlusal veneers

Group	Mean ± SD	Mean difference	p-value	95%CI	
				Lower limit	Upper limit
Retentive	6550.34±1738.04	-678.15	0.310	-2022.00	665.69
Non-retentive	5872.19±1152.15				

SD: Standard deviation

Table 3. Failure mode distribution for retentive and non-retentive occlusal veneers

Group	Type of fracture		
	RF	RF+EF	RF+EF+DF
Retentive	3	1	7
Non-retentive	2	2	7

RF: Fracture in the restoration; RF+EF: Fracture in the restoration and enamel; RF+EF+DF: Fracture in the restoration, enamel, and dentin

Therefore, the first part of the null hypothesis was accepted. These findings agree with those of Angerame et al. [7] who showed that the finish line design did not influence the fracture resistance of occlusal veneers.

In another study, Emam et al. [22] assessed the fracture resistance of occlusal veneers with two preparation designs. A significant difference in fracture resistance was observed for different materials, but no substantial impact of preparation design on fracture resistance was found. This result is consistent with the current study, although in the study conducted by Emam et al. [23] the specimens were exposed to lower frequency of cyclic loading compared to the present study.

In the current study, one specimen from the NR group fractured during dynamic loading. The increased fracture resistance observed in R veneers may be attributed to the larger surface area between the restoration and the tooth structure, which can impact fracture resistance. However, Huang et al. [24] demonstrated that preparation design influenced fracture resistance, with full crowns displaying the lowest fracture resistance. It was concluded that as the number of restored axial walls increased, the fracture resistance decreased, and the maximum principal stress within the restoration increased.

The fracture resistance of occlusal veneers in this study was above the average value for lithium disilicate (e.max Press) occlusal veneers reported by Clausen et al [25]. Sasse et al. [26] reported the fracture resistance of occlusal veneers fabricated from lithium disilicate ceramic blocks (IPS e.max CAD) to range from 1452 to 2570N. Angerame et al. [7] reported the fracture resistance of maxillary molars as 2395.01±150.96N for the shoulder finish line and 2408.39±112.66N for the chamfer finish line. The differences in fracture resistance reported by different studies may be explained by factors such as etching and cementation techniques, type of bonding substrate (enamel or dentin), occlusal surface area, ceramic thickness, loading cycles, and magnitude of the applied vertical load, all of which have a substantial role in determining the survival of the tested specimens [27].

The second part of the null hypothesis was rejected, as a statistically significant difference was observed between the marginal and internal gaps of the R and NR occlusal veneer groups. This contrasts with the findings of Emam et al. [22], where no statistically significant difference was detected in the marginal gap measurements between the two preparation designs. Marginal and internal fit are essential for the success of indirect restorations. The range of marginal gap for the R occlusal veneers was found to be greater than that for the NR occlusal veneers. Furthermore, the internal gap of the R occlusal veneers exceeded that of NR group. However, the gaps in both types remained within the clinically acceptable range, aligning with the findings of other studies [28-31].

Tooth anatomy and preparation design significantly affect the clinical service and integrity of prosthetic restorations [32]. This study used human natural teeth as the bonding substrate, providing a beneficial match to the clinical circumstances regarding bonding abilities, fracture resistance, and elastic properties. Additionally, to simulate physiological natural tooth mobility, a 0.25-mm-thick silicon was applied on the roots to simulate the periodontal ligament, which plays a crucial role in shock absorption and stress distribution of masticatory forces into the alveolar bone [33,34]. Thermocycling and dynamic loading were used to simulate real intraoral conditions. The preparation design followed clinical guidelines for minimally invasive restorations [35]. As stated by Al. Akhali et al. [36], a 120-degree angle connecting the buccal and lingual cusp angles (mesiobuccal and distobuccal slopes), with all angles rounded, was designed. This design choice was made because the occlusal surface of premolar teeth has sharper slopes and is smaller than that of molars; therefore, molar teeth were used instead. For molar teeth [6,36], the preparation design was standardized with cusp inclinations at a 150(±10)-degree angle with rounded angles [26,37]. This design also aimed to simulate the worst-case scenario for NR veneers, where flatter occlusal surfaces would make veneer placement more difficult.

The CAD/CAM wax pattern technique was employed in this study to fabricate the restorations. Previous research has indicated that the traditional wax pattern technique produces larger marginal gaps compared to the CAD/CAM technique [2]. This could be attributed to the inherent flaws in natural wax employed in traditional wax patterns, such as brittleness, elastic memory, high coefficient of thermal expansion, and thermal sensitivity [12]. This study used heat-pressed lithium disilicate, as previous research has demonstrated better marginal adaptation in heat-pressed lithium disilicate restorations than those fabricated using CAD/CAM [38].

The silicone replica technique was employed in this study to assess the internal and marginal gap of the restorations. This method is relatively straightforward and cost-effective, and allows direct measurement within the oral cavity. However, deformation during the procedure may occur [16].

In terms of failure mode, the present study evaluated failures visually, similar to studies by Andrade et al. [36] and Angerame et al [7]. In this study, most failures were classified as Type III (fractures involving the restoration, enamel, and dentin), accounting for 63.63% of cases. Type I failures (fractures confined to the restoration only) and Type II failures (fractures involving both the restoration and enamel) were observed at frequencies of 22.72% and 13.63%, respectively. These findings suggest that bonding to enamel provides greater fracture resistance compared to bonding to dentin.

Huang et al. [24] reported that most fracture patterns observed in specimens were cohesive fractures within the ceramic, with no involvement of the tooth structure. They attributed this to the tensile stresses primarily focusing on the brittle ceramic material, leading to cohesive fracture of the ceramic.

This study prepared the thickness of occlusal veneers according to the manufacturer's instructions to ensure minimally invasive preparation of tooth structure. Additionally, the bond strength of resin cement to enamel is higher and predictable compared to bonding to dentin due to the higher mineral content of enamel [39]. Additionally, a fracture resistance similar to that of thicker occlusal veneers bonded to dentin has been exhibited by thin occlusal veneers bonded to enamel [40].

Study limitations and future recommendations

The primary limitation of this study was the unavailability of certain materials. Furthermore, the storage medium did not replicate the oral environment; saliva would have been preferable to water before thermocycling. Future research should evaluate varying material thicknesses and employ a higher cyclic loading of up to 1,200,000 cycles.

CONCLUSION

Within the limitations of this in vitro study, the results indicated that occlusal veneers with R preparation design demonstrated insignificantly greater fracture resistance than NR veneers. Significantly larger marginal and internal gaps were observed in the R preparation group. However, the gap values in both groups remained within the clinically acceptable range.

CONFLICT OF INTEREST STATEMENT

None declared.

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