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Abstract

Purpose: To estimate the marginal adaptation and failure load of hybrid ceramic 'Vita Enamic' crowns with two margin designs, shoulder and feather-edge after thermomechanical fatigue. **Patients and methods:** A typodont mandibular first molar was selected. Exocad software was used to perform standard preparations of Vita Enamic ceramic crowns with two different margin designs; the first was prepared with a shoulder margin configuration, group (S) and the second was prepared with a feather-edge margin configuration, group (FE). Each prepared design was duplicated 15 times to form a total of 30 epoxy resin replicas ['$n = 15$' for shoulder (S) group and '$n = 15$' for the feather-edge (FE) group]. A total of 30 Vita Enamic crowns ($N = 30$) were designed and constructed using computer-aided design/computer-aided manufacturing machine. All crowns were adhesively bonded to their corresponding epoxy resin dies by using self-adhesive resin cement and then subjected to thermomechanical fatigue. Finally, perpendicular marginal space and failure load were gauged. **Results:** Shoulder margin 'group S' registered lower average perpendicular marginal space (68.075 ± 5.60 μm) as well as a higher average failure load value (1676 ± 80.34 N) compared with feather-edge margin 'group FE' (84.138 ± 2.78 μm) (1355.39 ± 274.85 N), respectively. **Conclusion:** For Vita Enamic ceramic crowns, both marginal adaptation and failure load of different margin designs conform to the range that is clinically approved.

Keywords: Failure load, Feather-edge margin, Marginal adaptation, Shoulder margin, Vita Enamic

1. Introduction

Conventional tooth preparation for a prosthetic crown with the use of shoulder and chamfer as horizontal finish lines has been widely used in practice, because of their presumed advantages in avoiding over contoured restorations and marginal overhangs, resulting in lab-clinician communication improvement and workflow enhancement [1]. However, it has always been considered invasive in nature since it leads to the inevitable irreversible loss of tooth-hard tissues. In the case of tooth preparation with vital dental pulp, there is always the risk of irritation, inflammation, necrosis, and subsequent endodontic therapy in the future [2].

So, over the years, many approaches have been proposed to create tooth preparation techniques that conserve and save as much of the healthy tooth structure as possible. Nowadays, minimally invasive techniques are commonly employed [3]. Tooth preparation devoid of a clear finish line offers a more preservative substitute for the typical conventional finish line, with countless vocabularies used to label this procedure, such as edgeless, shoulderless. This procedure is commonly advised in cases of periodontal-affected abutments as it may be more conservative when compared with horizontal preparation [4].

The fundamental goal of reconstructive dentistry is to adopt a minimally invasive, conservative approach with increased predictability and improved quality in teeth treatment found in both the anterior and posterior areas, with properly returning form, function, and cosmetic excellence while also still honoring the biological structures [5]. This has been achieved

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through the rapid development of new ceramic materials as well as computer-aided design/computer-aided manufacturing (CAD/CAM) systems [6].

Materials that have mechanical qualities similar to those of healthy teeth have been recently introduced, and they have increased the restorative system's durability. One illustration would be hybrid ceramics, which are ceramic materials that have been infused with polymers to blend the qualities of both ceramic and polymer. A hybrid structure with two interpenetrating networks of dominant ceramic and a reinforcing composite made up the so-called double network hybrid ceramic material [7]. These materials combine some benefits of composite resins, such as low abrasiveness, flexural characteristics, resilience, high fracture strength, and the capacity for intraoral healing, with some advantages of ceramics, such as color stability and longevity. Furthermore, it is a novel dental restorative material that has a moderate brittleness index, making it a good fit for CAD/CAM [8].

The main requirements for the success of any fixed restoration include precise marginal fit, fatigue resistance, and good fracture strength [8]. The restoration's internal edge and the reduced tooth may separate as a result of an inappropriate fit. This area is more vulnerable to adhesive cement dissolution in oral fluids, which can lead to microbial plaque accumulation with the progress of gingival irritation and caries terminated with pulpal injuries [9].

It is worth mentioning that the clinical longevity of the fixed restoration is directly proportional to its fatigue resistance and fracture strength. Any restoration may fracture suddenly from a single concentrated overload, but multiple cycles at low loads and damage accumulation can also alter their durability, thus reducing their service life [10].

Since the introduction of vertical preparation for hybrid ceramic crowns in prosthodontics, there has not been enough research done on how well these preparations marginally fit and how resistant they are to fracture in comparison to horizontal preparations, particularly after thermomechanical fatigue. That is why it was necessary to perform the present study in order to compare both designs. This study's nil hypothesis was that there would not be a distinction in margin fit and failure load of Vita Enamic crowns constructed with either horizontal or vertical margins.

2. Patients and methods

2.1. Ethical consideration

The current study was granted approval under Code (REC-CR-24-01) by the Research Ethics Committee (REC) of the Faculty of Dental Medicine for Girls, Al-Azhar University.

2.2. Sample size calculation

G power statistical power analysis tool (version 3.19.7) was used to determine the number of samples based on previous studies [2,11] and it was calculated as a total ($N = 30$) full coverage crown. This sample size perceived a huge 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 three-dimensional printed dies

To create a digital replica of the tooth, a typodont mandibular first molar was selected, coated with light reflecting powder (Occlutec, Scanspray, Renfert, USA) and scanned (Ds Mizar, Italy). After that, the process of scanning was duplicated to get two files for the same tooth. Data were imported into the Exocad software (Exocad software GmbH, Germany) in order to create standard Vita Enamic ceramic crown preparations with two various margin configurations.

Both preparations were designed with the same proportions of 8 mm gingival diameter, 5 mm occluso-cervical height with occlusal reduction (1.5–2 mm) of nonfunctional and functional cusps respectively, (1.2–1.5 mm) axial reduction except for the dissimilar margin configuration [12,13]. One was designed with a shoulder margin of (1 mm) and the other was designed with a feather-edge margin of (0.2 mm), as in Diagram 1.

The designs were kept in the shape of 'stereolithography (STL)' file. A three-dimensional (3D) printing apparatus (ANYCUBIC Photon Mono SE, China) was used to print the resin dies after loading the STL file onto it.

2.4. Manufacturing and duplication of epoxy resin dies

A plastic cylinder (1.6 cm height and 1.5 cm diameter) loaded with type IV dental stone (Kalrock, Mumbai, India) was used in the stone blocks' construction by embedding each prepared 3D printed resin die in the center of the cylinder, exposing 2 mm below the cervical line, allowing the stone to set before being finished and smoothed (Fig. 1A).

Duplicating addition silicon material (Replisil 22, Dent-e-con, Germany) was used in order to create the silicon mold for the prepared 3D printed dies. 30 epoxy resin replicas (15 dies for shoulder 'S' margin and 15 dies for feather edge 'FE' margin) were

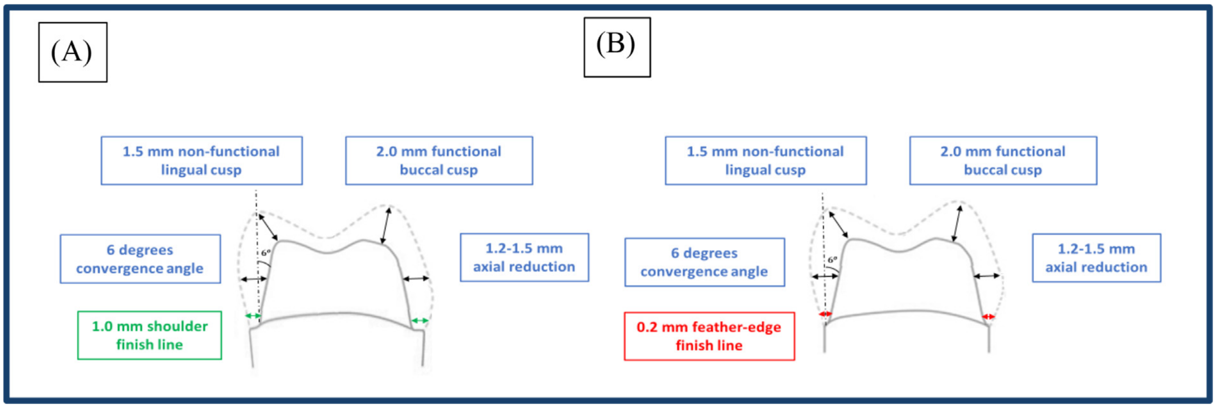

Diagram 1. Criteria of preparation with two margin configurations; (A) Shoulder margin configuration. (B) Feather-edge margin configuration.

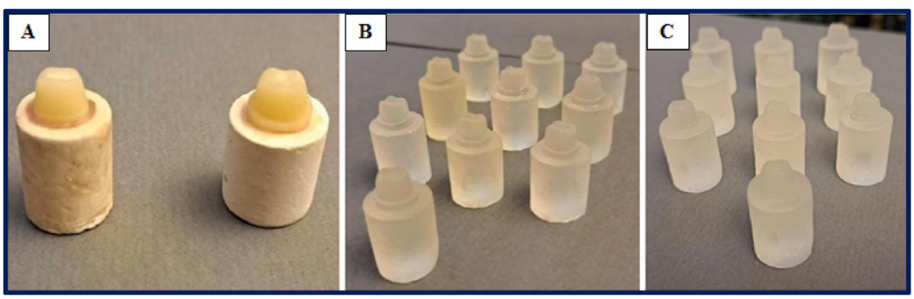

Fig. 1. Manufacturing and duplication of epoxy resin dies; (A) Prepared three-dimensional printed resin teeth embded in type IV dental stone (B) Epoxy resin dies for shoulder margin group. (C) Epoxy resin dies for feather-edge margin group.

created by duplicating each prepared design. Then epoxy resin material (EgyPro epoxy resin, Egypt) was mixed and spilled out in the silicon mold and left until complete hardness. Finally, after complete hardness, the epoxy resin dies were detached from the silicon mold (Fig. 1B and C).

2.5. Samples' grouping

A total of 30 epoxy dies were used in the present study. Epoxy dies were divided into two groups according to margin configurations; group (S): 15 epoxy dies with shoulder margin (1 ± 0.1 mm) (control group). Group (FE): 15 epoxy dies with feather-edge margin (0.2 ± 0.05 mm).

2.6. Construction of Vita Enamic ceramic crowns

Scanning of the dies was perfprmed utilizing an intraoral scanner and kept as 'STL' file that transported to design software for fabricating the restoration. Milling of the crowns was done underneath wet treatment by means of the CEREC Inlab MC XL milling machine (Dentsply Sirona, USA). After finishing the crowns' milling, all the crowns were checked and verified with their corresponding dies. Finally, a clinical finishing kit and polishing paste were used for finishing and polishing the crowns according to the manufacturers' instructions.

2.7. Bonding of the crowns

The intaglio surface of every crown was surface treated using the procedures listed below [8]: A) Application of the hydrofluoric acid (9 % concentration) for 10 s. B) Rinsing of the fitting surface with water and dryness until a chalky appearance was confirmed. C) Silanization of the fitting surface by applying a silane coupling agent for 60 s followed by dryness.

In accordance with the manufacturer's instructions, each crown was cemented on its matching die using 'Thera-Cem' resin cement. A specially designed cementation device was used to maintain a static load on each crown until the complete setting of cement. Cementation procedure started with sliding of the vertical bar in a downward direction till it touched the restoration that seated on the lower compartment of the device and a 3 kg static load was applied on the upper disc shaped portion of the device for 5 min [14]. Light curing was applied for 20 s on each crown surface and any extra cement at the margin was removed.

2.8. Thermomechanical fatigue

Four station multi-modal 'SD Mechatronik' chewing simulator coupled with a thermo-cycle protocol was used to perform mechanical aging via cyclic loading. The four chamber 'SD Mechatronik' chewing simulator replicates simultaneous vertical and horizontal movements under thermomechanic conditions. In accordance with the requirements, each sample underwent 75 000 cycles of loading in the chewing simulator device at the same time as temperature cycles between 5 °C and 55 °C, which replicated a 6-month clinical condition [9].

2.9. Testing procedures

2.9.1. Marginal fit

The measured perpendicular marginal space at particular sites was used to evaluate the marginal fit of the fabricated vita-enamic crowns. The margin fit was assessed at 12 predetermined points, three points at each surface with fixed distance between points '3 mm' in buccal and palatal surfaces and '2.5 mm' in mesial and distal surfaces [4]. Margins were photographed at a fixed magnification of 50×. The system of digital image analysis (OmniMet image analysis software) was used to measure and assess the gap width.

2.9.2. Fracture resistance

Through the recording of sample failure under compressive force, fracture resistance was ascertained. Epoxy resin dies were anchored to the immobile 'static' head of the universal testing machine (Instron model 3345, Norwood, USA) and a continuous static load (5 KN) using a stainless-steel ball bounded to the upper movable head of the testing machine was applied. Axial compression force was directed to the centre of the occlusal surface till sample failure.

Failure mode analysis was executed using a magnifying lens (10×) to classify the failure mode according to Burk's classification [15]:

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

2.10. Statistical analysis

The statistical analysis was conducted using IBM Corp.'s SPSS version 20 (Armonk, NY). The mean, standard deviation, confidence intervals, and range were used to summarize the numerical data. The analysis of variance test was utilized to perform comparisons between groups. Significant P values were defined as less than or equal to 0.05.

3. Results

3.1. Marginal fit: (perpendicular marginal space 'μm')

Shoulder margin 'group S' recorded lower average perpendicular marginal space compared

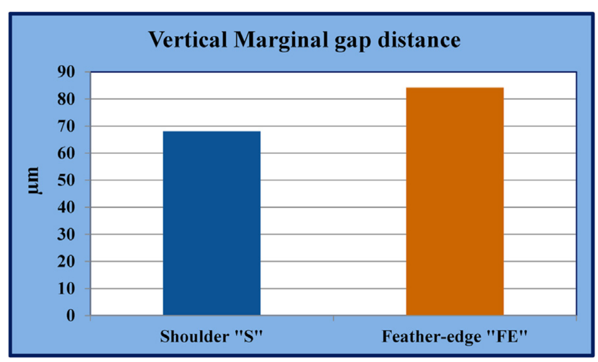

Fig. 2. Bar chart illustrating vertical marginal gap distance (μm) in both groups.

Table 1. Mean values, Standard deviation (SD) and statistical analysis of perpendicular marginal space (μm) as well as failure load (N) of both groups, (Independent T-test).

Vertical marginal gap				
Groups	Mean ± SD (μm)	Range	t value	P value
Shoulder 'S'	68.075 ± 5.60	62.48–73.68	5.744	<0.00043*
Feather-edge 'FE'	84.138 ± 2.78	81.36–86.92		
Failure load				
Groups	Mean ± SD (N)	Range	t value	P value
Shoulder 'S'	1676 ± 80.34	1595.66–1756.34	−2.49	0.041*
Feather-edge 'FE'	1355.39 ± 274.85	1080.54–1630.24		

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

with feather-edge margin 'group FE' with a statistically significant variance among both groups (*P* <.00043) as revealed in Table 1 and Fig. 2.

3.2. Fracture resistance (failure load 'N')

Shoulder margin 'group S' recorded higher mean failure load value compared with feather-edge margin 'group FE' with a statistically significant variance among both groups (*P* <0.041) as revealed in Table 1 and Fig. 3.

3.2.1. Mode of fracture analysis

(i) Regarding the shoulder margin design, group (S):
   (a) Code (4) was the most common fracture mode observed with fracture more than half of the crown, followed by severe fracture of the epoxy resin die and/or a crown (Code 5).
   (b) No sample recorded fracture mode with (Codes 1, 2, and 3).

(ii) Regarding the feather-edge margin design, group (FE):
   (a) The most common fracture mode was observed with severe fracture of the epoxy resin die and/or a crown (Code 5), followed by fracture of more than half of the crown (Code 4).
   (b) No sample recorded fracture mode with (Codes 1, 2, and 3).
   (c) Chi square test showed that the difference between groups was statically significant. Data are represented and shown numerically in Table 2.

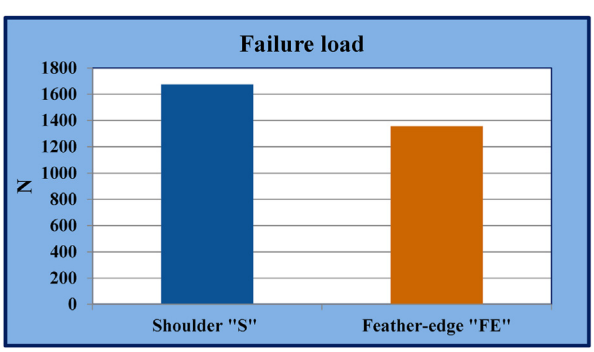

Fig. 3. Bar chart illustrating failure load (N) in both groups.

4. Discussion

The prime challenge of restorative dentistry is how to attain an excellent esthetic outcome while preserving tooth structure through minimally invasive preparation techniques. Minimizing and reducing tooth preparation encourages the maintenance of the tooth structure and dento-enamel junction, which has a significant role in the stress redistribution, resisting crack propagation, and extending the durability of teeth [16].

Many dental ceramics have been suggested and recommended in order to satisfy the patients' esthetic expectations, mechanical needs, and functionality. The progress made in material development has enabled clinicians to perform more conservative tooth preparations, removing less tooth structure during the procedure, particularly regarding single restorations [17].

Ceramics and composites are two common types of restorative materials available for use with CAD/CAM systems. Ceramics have excellent mechanical, optical and biocompatibility properties. However, they are fragile, rigid, and hard to repair [7]. On the other hand, composites can be easily manipulated, repaired, more flexible, and less abrasive on the antagonist tooth. Still, their low wear resistance and difficulty obtaining good polish are their two main disadvantages [18].

Therefore, manufacturers have thought of hybrid ceramics that combine both materials to simulate mutually the mechanical and optical features of a natural tooth. The hybrid structure of these materials would also reduce the restoration's fragility and superficial hardness, allowing for milling in a shorter time and predicting better clinical results [19].

Furthermore, horizontal margins are usually chosen for all-ceramic crowns bonded to prepared teeth. The suggested finish line thickness for all-ceramic crowns has included a range of 0.5–1.0 mm [1]. However, vertical margins for Vita Enamic crowns have recently been suggested as a less invasive preparation design recommended for periodontally damaged teeth and are being used as fixed prosthesis abutments. Additionally, it may be a less intrusive option than the horizontal margin for carious teeth in the cervical third of the clinical crown, teeth that have undergone endodontic

Table 2. Comparison of fracture mode assessment between groups (Chi square test).

Groups	Mode of fracture					*P* value
	Code 1	Code 2	Code 3	Code 4	Code 5	
Shoulder 'S' *N* (%)	0	0	0	9 (60)	6 (40)	0.029[a]
Feather-edge 'FE' No. (%)	0	0	0	3 (20)	12 (80)	

[a] Significance level less than or equal to 0.05, ns = nonsignificant.

treatment, and teeth that are significant in children with high pulp horns [3].

As a result, minimally layered ceramic restorations are increasingly advised. It is crucial to remember that there might be significant variations in marginal fit and fracture resistance for various ceramic systems when crucial factors like margin configuration, cement type, and material type are taken into account [20]. Therefore, in the current study, one material (Vita Enamic) with different margin configurations (horizontal 'shoulder' margin as the control group versus vertical 'feather-edge' margin as the tested group) was selected to examine the outcome of these margin configurations regarding the marginal fit and failure load of this restoration.

In the current study, to standardize the different margin configurations, preparations were designed and then 3D printed using a 3D printing machine. They were duplicated to obtain 15 epoxy resin dies for each margin design. Since the abutment's modulus of elasticity plays a key role in assessing the resilience of all ceramic restorations to fracture, epoxy resin dies have been offered as a substitute for natural teeth due to their similar elasticity to dentin (12.9 GPa) [21].

A thermomechanical fatigue procedure was used to replicate oral cavity conditions by subjecting each sample to 75 000 cycles of loading, which simulates a 6-month clinical situation [9]. In the current study marginal fit and fracture resistance were assessed afterward thermomechanical fatigue, since it is one of the utmost imperative features influencing the long-term realization of the restoration.

Inadequate marginal fit between restorations and teeth can lead to microleakage, cement breakdown, and carious lesions, all of which can shorten the restoration's lifespan and ultimately cause failure [20]. The luting agents' viscosity effect was lessened by carefully controlling cementation while maintaining a steady load [14]. A digital stereomicroscope was utilized to evaluate marginal gap in this existing research because it is regarded as a noninvasive investigative device. Both groups in the current study's measure of the vertical marginal gap of Vita Enamic ceramic crowns fell within the clinically approved variety of 40–120 μm, according to other studies [7,16,22], as shown in Table 1 and Fig. 2.

The outcomes of perpendicular marginal space measurement of Vita Enamic ceramic crowns with both margin configurations showed that the shoulder margin 'group S' recorded inferior marginal space compared with the feather-edge margin 'group FE'. This was in accordance with a previous study [9]. This might be because the force applied in the shoulder design, at the axio-gingival angle is perpendicular to the margin's surface; in the feather-edge design, however, the force applied at the surface's line angle is smaller, resulting in less pressure being applied. As a result, the crown restoration's seating is not as good as it is in the shoulder design [23].

Yet, the current study's findings conflict with that of another study [24]. This was clarified by the reality that whenever the restoration margin terminates at an acute angle, the distance between restoration margin and tooth becomes smaller.

It is essential for restorative materials to be fracture resistant in order to anticipate both the clinical examination and failure degrees [13]. The behaviour of the hybrid ceramic restorations when mechanical forces are applied in the oral cavity remains unclear. That's why fracture resistance was also evaluated in this current study, particularly after thermomechanical fatigue.

Divergent opinions exist on the amount of clinically appropriate mean bite force that can be given to natural teeth in the molar region within the oral environment. A previous study revealed that the median extreme bite forces diverse among 216 and 847 N; the utmost bite stress was in the first molar expanse: where it was 807 N for mankind and 650 N for womankind. These values have the potential to rise to 965 N during object biting [25]. The mean failure loads of both groups in the current investigation exceeded the range of realistic occlusal forces. Consequently, it may be presumed that all samples that were evaluated have the capacity to tolerate the highest intraoral masticatory forces.

The outcomes of the failure load of Vita Enamic ceramic crowns with both margin configurations showed that the shoulder margin 'group S' recorded a statistically significant higher average of failure load than the feather-edge margin 'group FE'. Table 1 and Fig. 3. This correlates with another study that found the horizontal designed crowns had higher fracture load than the vertical designed crowns [26]. It could be as a result of the shoulder margin's stress distribution pattern, which lessening stresses concentration on the axial walls because occlusal stresses are tolerated by the circumferential shoulder [27]. Moreover, fracturing occurs at a higher load in response to increases in the axial wall thickness and crown margin. This was consistent with other research that found a thickening of the crown margin was the reason for crown fracture at a higher load [28].

On the contrary, the current study disagrees with a preceding study showing that the vertical margin design noted a higher average of failure load than that of the horizontal margin design [13]. This promising outcome was associated with the stress distribution method by rising and exceeding the force on the restoration at the feather-edge margin design, which diffused to the walls of axial surfaces rather than the supporting die margin, causing concentration of the stresses on the surface of the occlusal part of the restoration rather than the margin region [12,29].

It is important to note that fracture mode analysis adds clinical value to in-vitro studies and provides a valuable tool to estimate the restorability of a tooth following restoration failure. In the current study concerning fracture modes related to shoulder margin configuration, 60 % of the sample recorded fractures of more than half of the crowns 'code 4' and 40 % recorded sever fracture of the crown, (Table 2), which agrees with the findings of a previous study [3] taking into account that the longevity prognosis of the restored teeth is improved by fractures that are restricted to the restorative material since a new crown may be simply inserted in place of the old one. The tooth-restoration structures have similar and compatible elastic moduli, prone to bend fewer below weight and dispense pressures more uniformly to protect underneath tooth structure from destruction [15].

On the other hand, 80 % of the samples in the feather-edge group showed catastrophic fractures which included a sever fracture of crown (code 5) (Table 2). This is in accordance to former study [12] which reported that the feather-edge margin carried the occlusal stresses which caused concentration of stresses on a small area of the finish line, indicating one of the weakest regions of the crown structure rather than a wide area of the occlusal surface resulting in early failure of restoration.

There were certain drawbacks with the current investigation; horizontal marginal gap was not examined, and the perpendicular marginal space was only recorded at the present investigation. Furthermore, while loads are delivered in multiple directions in clinical settings, only one compressive load per fracture is taken into account.

4.1. Conclusion

With respect to the constraints of the present research, it may be said that:

(a) Different margin configurations are crucial aspects that determine their marginal fit and failure load.
(b) For Vita Enamic ceramic crowns, both marginal fit and failure load of different margin configurations fall within the clinical acceptance ranges.
(c) Shoulder margin configuration of Vita Enamic ceramic crowns has a superior marginal fit compared with feather-edge margin configuration. Also, feather-edge margin configuration compromises the fracture resistance compared with shoulder margin configuration.

4.2. Recommendations

Clinical studies are recommended to validate the reliability of using both preparation designs and this hybrid ceramic material. Different margin configurations 'feather edge and shoulder' with Vita Enamic ceramic crowns can be safely used in clinical practice regarding marginal fit and fracture resistance.

Ethics information

The current study was granted approval under Code (REC-CR-24-01) by the Research Ethics Committee (REC) of the Faculty of Dental Medicine for Girls, Al-Azhar University.

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Conflicts of interest

There are no conflicts of interest.

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