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IN VITRO EVALUATION OF THE MARGINAL ADAPTATION OF MONOLITHIC CERAMIC CROWNS FABRICATED WITH DIFFERENT MARGIN DESIGNS USING NOVEL CAD/CAM MATERIAL AFTER THERMOMECHANICAL AGING

Hanaa Nassar* *and* Ebtesam Osama Abo El-Mal**

ABSTRACT

Objectives: To evaluate the marginal adaptation of premolar monolithic ceramic crowns fabricated from novel advanced lithium disilicate CAD/CAM blocks with two different finish line designs (feather edge finish and deep chamfer finish lines), both before and after exposure to thermomechanical aging.

Materials & methods: Twenty-two maxillary premolar teeth were endodontically treated, and divided into 2 groups according to finish line design; deep chamfer finish line (Gr_C) group (n=11), and feather-edge finish line (Gr_V) group (n=11). Following teeth preparation, all crowns were milled from advanced lithium disilicate CAD/CAM blocks (CEREC Tessera) and adhesively bonded to their corresponding teeth using adhesive resin cement then, subjected to thermomechanical aging. Marginal gap was assessed using digital microscope and image analysis software.

Results: feather-edge finish line showed the lowest marginal gap mean values (29.07± 8.05), while deep chamfer finish line recorded the highest marginal gap mean values after artificial aging (52.97± 2.79). The results were statistically significant before artificial aging, but non-significantly different after thermal cycling.

Conclusion: Advanced lithium disilicate (CEREC Tessera) monolithic crowns with feather-edge margins showed superior margin adaptation to those fabricated with deep chamfer margins and can offer a more conservative solution for reconstruction of severely compromised teeth.

KEYWORDS: Marginal adaptation, feather-edge finish line, advanced lithium disilicate, monolithic ceramic crowns, endodontically treated premolars.

* Assistant professor, Department of Fixed Prosthodontics, Faculty of Oral and Dental Medicine, Ahram Canadian University

** Assistant professor, Department of Endodontics, Faculty of Oral and Dental Medicine, Ahram Canadian University

INTRODUCTION

The ideal protocol for restoring endodontically treated teeth was always an area for research and continuous debate in literature. [1] One thing was a point of agreement in most literatures which is that the clinical longevity and success of any restoration for endodontically treated teeth relies on utilizing the latest materials with sound clinical protocol. [2]

Endodontically treated maxillary premolars exhibit all the eight possible canal configurations described in the Vertucci classification system.[3] These variations in the numbers and configurations of roots and root canals are the reason why premolars are ones of the most challenging teeth for endodontic treatment. In addition, there is always high incidence of procedural errors that can lead to more deterioration of compromised teeth. [4] many literatures reported that clinical survival of endodontically treated premolars was improved by cuspal coverage with indirect restorations (full coverage restorations were mostly reported), as they offer proper protection for the remaining tooth structure from the oral environment and provide coronal seal. [1,5]

Full coverage ceramic preparations are generally classified into two main types: horizontal preparations, with definite finish line such as radial shoulder and deep chamfer margins, and vertical preparations which utilize a non-definite finish lines like feather-edge margins. Vertical preparations or as also known as biologically oriented preparation technique (BOPT), was suggested in many literatures as a more conservative preparation to use in compromised teeth with insufficient tooth structure. [6,7] In addition, many studies advocated the use of BOPT in periodontally compromised teeth based on their clinical findings of superior periodontal tissue response. [8,9]

The quest for optimum ceramic material that offers strength, aesthetics and excellent biological response will never stop. [10] Advanced lithium disilicate is a newly introduced glass ceramic material, that possesses a unique microstructure of 0.5 µm long lithium disilicate crystals embedded in a glassy matrix with 0.2–0.3 µm platelet like lithium alumino silicate crystals (virgilite). This comprises for biaxial flexural strength of 700 MPa, which is considered the highest among all glass ceramics. [11]

Margin adaptation is a crucial factor for clinical success of indirect restorations. Poor marginal adaptation can have a detrimental effect on the restoration strength, with increased risk of leakage, recurrent caries and periodontal diseases.[12] Clinically acceptable marginal gap values have been set by McLean and von Fraunhofer to be 120µm.[13]

Therefore, the aim of this study was to investigate the marginal adaptation of maxillary premolar monolithic CAD/CAM ceramic crowns fabricated from novel advanced lithium disilicate and virgilite blocks with two different finish line designs (feather edge finish and deep chamfer finish lines), both before and after exposure to thermomechanical aging. The null hypotheses were that, there would be no difference in marginal gap values between the two tested margin designs or between before and after thermomechanical aging.

MATERIALS AND METHODS

The protocol for this study has been registered and exempted by Institutional Review Board Organization IORG0010868, Faculty of Oral & Dental Medicine, Ahram Canadian University. Research Number: IRB00012891#76.

Sample size for this study was calculated using Independent t-test on G statistical power analysis program (G. power version 3.1.9.7), relying on a previous study by El-Damaty *et al,* 2020 as reference. [19] If mean ± standard deviation of control group is 28.4 ± 2, while mean ± standard deviation of intervention group is 34.5 ± 6.5, the study needed a minimum of 9 samples in each group (18 in both groups). Total sample size was increased to 11 samples per group (Total = 22) to compensate for 20 % drop-out.

Selection and preparation of study samples:

Twenty-two sound maxillary first premolars that were extracted due to periodontal disease, with two root canals and mature roots were selected. Teeth with any resorptive areas or fracture lines were excluded. Teeth surfaces were examined for any cracks or decay, then teeth length was measured by digital caliper (Mitutoyo IP-65, Japan) for an average of 15 mm ±1mm. Teeth were cleaned from stains and debris with ultrasonic scaler (Cavitron GEN- 119; Dentsply, York, PA), and stored in distilled water at room temperature till use. [14]

Teeth were inserted into a custom-made cylindrical-shaped mold with dimensions of 4x4cm filled with self-curing acrylic resin (Acrostone; Acrostone dental plant, Egypt), up to 2mm below the cementoenamel junction to allow for proper margin visualization and assessment.

Endodontic procedure:

Oval access cavity was prepared in buccolingual direction, and all the root canals were instrumented by the same operator using crown down technique and ProTaper Next files (Dentsply Malliefer, Ballaigues, Switzerland) according to manufacturer instructions. The master apical file in each tooth in both buccal and lingual canals was standardized to file size X3. Sodium hypochlorite irrigating solution between each file was used in alteration with EDTA gel (Meta, Biomed) as lubricant for the Ni/Ti files. After completion of mechanical preparation, a final irrigation with distilled water was done. Teeth were obturated with gutta percha size 30, 0.04 taper (Dentsply Malliefer, Ballaigues, Switzerland) using lateral condensation technique and resin-based root canal sealer (ADseal Meta Biomed South Korea).

All excess gutta-percha was removed from the pulp chamber, then access cavity walls were etched with 37% phosphoric acid (Etch-37, BISCO, USA) for 30 seconds followed by rinsing for 30 seconds and air drying for another 30 seconds. Universal adhesive (All-Bond Universal. BISCO, USA) was applied to the etched access cavity walls with micro-brush, left for 30 seconds to react then light cured for 20 seconds. Access cavity was completely filled with bulk-fill flowable composite (SDR® flow, Dentsply Sirona, Germany) to the occlusal surface level and light cured with light polymerization device (Elipar™ , 3M ESPE, USA) for 40 seconds.

Teeth preparation for monolithic ceramic crowns

All samples preparation was done by the same operator under 4.0x magnification surgical loups with 5500k LED headlight (UNIVET, Italy). In order to standardize the amount of reduction for the study samples, all teeth were scanned using Omnicam intraoral scanner (CEREC AC; Dentsply Sirona GmbH, Germany) prior to full coverage restoration preparation to allow for superimposition of the digital images from before and after preparation for a proper digital verification using CEREC Prep-check feature (Version 5.1.1, Dentsply Sirona GmbH, Germany). In addition, silicon index was done using polyvinyl siloxane hard duplicating material (Elite Double-22, Zhermack-Germany) for preparation checking.

Teeth were randomly divided into 2 experimental groups (n=11 each) according to the finish line design: Group_C: prepared with deep chamfer finish line 1mm thick, and Group_V (n=11): prepared with feather-edge finish line (Verti-prep) of 0.2mm thickness.

Preparation for deep chamfer group was done with a planner occlusal reduction of 1.5mm using double-cone diamond bur (FG811, Komet, Schaumburg, USA) held in high-speed handpiece (Synea WK-900 LT, W&H, Austria). Axial reduction of 1.2mm with circumferential deep chamfer margin of 1mm and 6°-8° convergence was done with tapered chamfer diamond bur (6856, Komet, Schaumburg, USA). For feather-edge group, planner occlusal reduction of 1.5mm using double-cone diamond stone, followed by axial reduction of 1.2mm with feather-edge finish line of 0.2mm (±0.05mm) and 6°-8° convergence was done using feather edge diamond bur (8862, Komet, Schaumburg, USA). All preparations for both groups were finally smoothed and polished with pointed white polisher (307, Komet, Schaumburg, USA).

All prepared teeth were checked with silicon index and periodontal probe, then re-scanned using Omnicam intraoral scanner for digital verification of the preparation with Prep-check feature. Any teeth with >0.02mm discrepancy were excluded.

Fabrication of monolithic crowns:

Final restorations designing was done by CEREC 3D software, version 5.1.1 (Dentsply Sirona GmbH, Germany). Standardized design with similar parameters and occlusal morphology was accomplished by copy & mirror feature. The cement space was set at 80µm. All restorations were milled from advanced lithium disilicate and virgilite CAD/CAM blocks (CEREC Tessera, Dentsply Sirona GmbH, Germany) using 4-axis wet milling/grinding machine MCXL (Dentsply Sirona GmbH, Germany). After finishing sprue area with ceramic polishing diamonds (Brasseler, USA), milled restorations were sprayed with glaze material (Dentsply Sirona Spray Glaze, Dentsply Sirona, Germany) then glaze fired in ceramic furnace Programat P3010 (Ivoclar Vivadent Inc., New York, USA) following the manufacturer instructions. After complete cooling, restorations were checked on their corresponding abutments for proper seating and marginal adaptation using surgical microscope (Zeiss OPMI-Pico DENT, Germany).

Adhesive cementation of restorations:

The intaglio surface of each restoration was first etched for 30 seconds with 9.5% hydrofluoric acid gel (Porcelain etchant, Bisco Inc, USA), followed by rinsing thoroughly with distilled water, then, ultrasonic cleaning in water path for 3 minutes as per manufacturer recommendations. Silane coupling agent (Porcelain primer, Bisco Inc, USA) was applied to the cleaned restoration fitting surface, left for 60 seconds, then air dried.

Teeth surface treatment was done first by etching with 37% phosphoric acid gel (Etch-37, BISCO Inc, USA) for 30 seconds, followed by rinsing and air drying. A coat of universal adhesive (All-Bond universal, Bisco Inc, USA) was applied to the etched surface and light cured for 20 seconds, then dual-cured adhesive resin cement (Duo-link®, Bisco Inc, USA) was applied to the fitting surface of each crown restoration, and restorations were cemented one restoration at-a time to their corresponding abutments under static finger pressure. After initial removal of excess cement pile, restorations were placed in a special loading device under 5kg load, and excess cement was completely removed under 4.0x magnification surgical loups, then 40 seconds light curing was done at each restoration surface. Samples were stored in distilled water at room temperature for 24 hours before thermo-mechanical aging.

Measurements of vertical marginal gap:

The cervical vertical marginal gap in each monolithic restoration was analyzed first before thermomechanical aging using USB Digital microscope (U500x Digital Microscope, Guangdong, China) with built-in digital camera at a fixed magnification of 40x and connected to an IBM compatible computer. Received images were analyzed using digital image analysis system (Image J 1.43U, National Institute of Health, USA) for assessment of the marginal gap. Vertical marginal gap was marked from the most cervical external restoration edge to the outermost edge of tooth finish. 4 shots were taken for each sample from all surfaces, vertical marginal gap was measured in microns at

3 equidistant landmarks along the circumference for each surface and measurement at each point was repeated three times [14] **(Figures 1 and 2)**. All obtained data were collected and tabulated for statistical analysis after thermomechanical ageing.

Thermomechanical aging:

Artificial aging was performed using masticator simulator (Robota automated chewing simulator; BILGE, Turkey) operating on servomotor (ACH-9075DC-T, AD-Tech Technology CO, LTD., Germany) and integrated with thermocycling protocol. Each sample was subjected to artificial aging simulating 6 months of clinical service through, 50 N cyclic loading for 75,000 cycle and thermal cycling for 5000 cycles at temperature of 5° and 55° with dwell time of 25 seconds in each path and 10 seconds lag time. [14,15]

Vertical marginal gap was re-evaluated after artificial aging using the same settings and reference points for each sample **(Figures 1 and 2)**. Finally, all data were collected and tabulated using Excel for Microsoft (version 365) for statistical analysis and comparison with gap measurements before artificial aging.

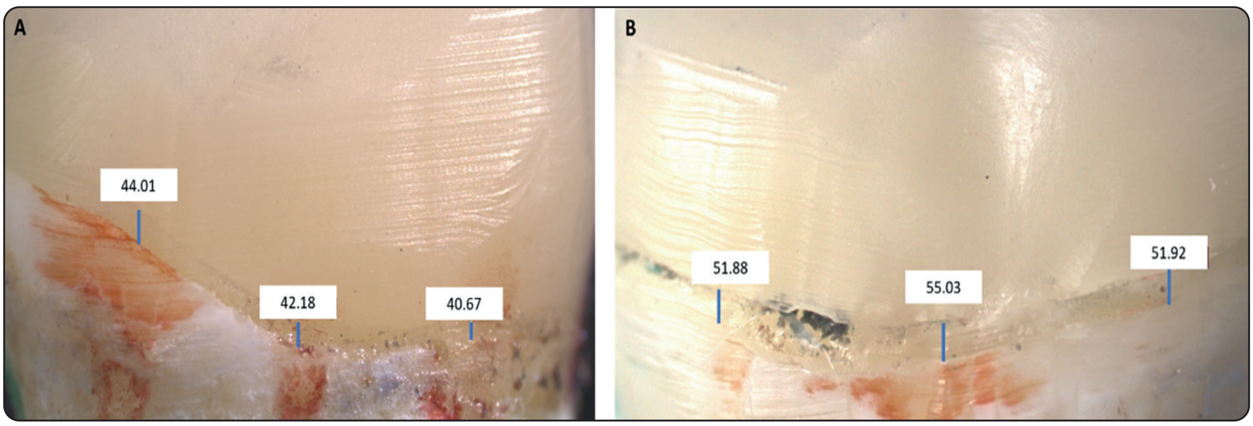

Fig. (1) Vertical marginal gap measurement for deep chamfer finish line; A: before thermomechanical aging, B: after thermomechanical aging

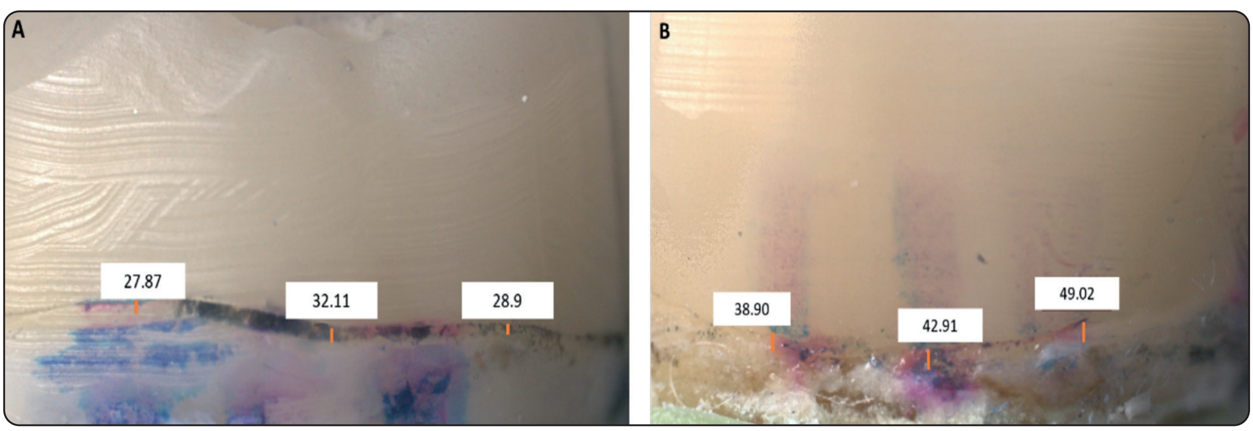

Fig. (2) Vertical marginal gap measurement for feather-edge finish line; A: before thermomechanical aging, B: after thermomechanical aging

Statistical analysis:

Student t-test was used to verify whether there was statistical difference between the groups and between artificially aged and non-aged groups. A Two-Way ANOVA test was performed to detect the influence of each variable (group and aging). Statistical analysis was performed using GraphPad InStat statistics software (version 3.06) for Windows. *P* values $\leq$ 0.05 were statistically significant in all tests. Sample size (n=11/group) was large enough to detect large effect sizes for main effects and pair-wise comparisons, with the satisfactory level of power set at 80% and a 95% confidence level**.**

RESULTS

Descriptive statistics of the mean and standard deviation of marginal gap measurements (μm) for both groups before and after thermomechanical aging are summarized in **(Table 1)** and graphically drawn in (**Figure 3).**

Deep chamfer group (Gr_C) recorded higher marginal gap mean values (***52.97± 2.79*** μm) after thermomechanical aging than before aging (***42.17±2.65*** μm) with mean difference (10.8) which is higher than least significant difference (LSD) = 6.68. This was ***statistically significant*** (p=<0.0001<0.05) as revealed by paired *t*-test in **(Table 1 & Figure 3).**

Feather-edge group (Gr_V) after thermomechanical aging recorded higher marginal gap mean values (***46.70±8.97*** μm) than before (***29.07± 8.05*** μm) with mean difference (17.63) which is higher than least significant difference (LSD) = 6.68. This was ***statistically significant*** (p=0.0005 < 0.05) as validated by paired t-test. **(Table 1 & Figure 3).**

Comparison for before and after thermomechanical aging: it was found that ***Gr_V*** generally recorded lower gap mean values than ***Gr_C*** mean value. This was ***statistically significant*** (p=0.0003< 0.05) before aging while ***non-significant*** (p=0.0626> 0.05) after aging as proved by unpaired t-test. **(Table 1 & Figure 3).**

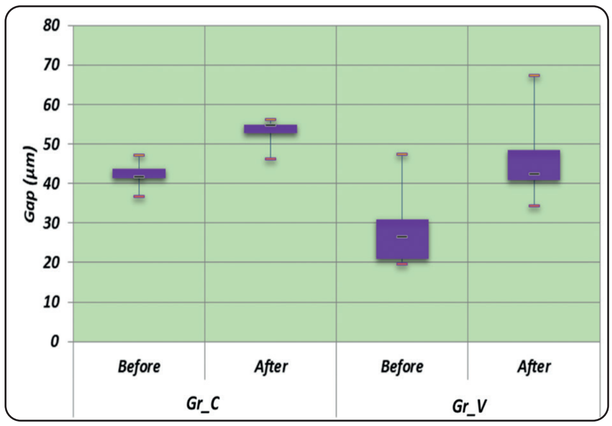

Fig. (3) Box plot comparing marginal gap mean values as function of main group before and after Thermomechanical aging.

Table (1): Marginal gap results (Mean values± SDs) as function of main group type before and after Thermomechanical aging.

Variable		Thermomechanical aging						Statistics
		Before			After			P value
		Mean ± SD	95% CI		Mean ± SD	95% CI		
			Low	High		Low	High	
Main group	Gr_C	42.17±2.65	39.72	44.61	52.97± 2.79	50.38	55.56	<0.0001*
	Gr_V	29.07± 8.05	21.62	36.52	46.70±8.97	38.41	54.99	0.0005*
Statistics	P value	0.0003*			0.0626 ns			

; significant (*p* < 0.05)** ***ns; non-significant (p>0.05) ***Least significant difference (LSD) = 6.68***

Total effect of margin design on marginal gap

Regardless of artificial aging, it was found that ***Gr_V*** recorded lower gap mean values than ***Gr_C*** mean value. This was ***statistically significant*** (p=0.0001 < 0.05) as revealed by two-way ANOVA test.

Total effect of thermomechanical aging on marginal gap

Irrespective of group type, it was found that aging ***significantly affected*** the marginal gap mean values (p=<0.0001 < 0.05) as demonstrated by two-way ANOVA, where the marginal gap after thermomechanical aging recorded higher mean value than before.

DISCUSSION

Establishing a harmonious relationship between indirect restorations and the periodontium while maintaining maximum conservation of the tooth structure has always been a challenge, and a crucial factor for clinical longevity and esthetic harmony. [17,18] Advances in CAD/CAM ceramic microstructure and development of high strength ceramics along side the introduction of BOPT encouraged both researchers and clinicians to test the available ceramic materials to find the most suitable for use in thin vertical preparations with feather-edge finish line. [19]

For years, horizontal margin designs like deep chamfer and rounded shoulder finish lines of 1-1.5mm thickness have been considered the optimal preparation for all ceramic restorations as recommended by manufacturers and reported in literatures. [17] On the other hand, there is a growing need for more conservative full coverage preparation especially in the cervical area where abutment strength could be majorly affected by excessive cutting. Moreover, maximum tooth conservation is crucial in certain conditions such as endodontically treated and periodontally compromised teeth.[8] Among endodontically treated teeth, maxillary premolars are the most susceptible to fracture due to their less than ideal anatomic form, position in dental arch and small crown volume compared to molars, which makes maximum tooth conservation even more necessary. [7]

This study aimed to investigate the marginal adaptation of maxillary premolar monolithic ceramic crowns fabricated from advanced lithium disilicate CAD/CAM blocks with feather edge or deep chamfer finish lines before and after exposure to thermomechanical aging.

Due to their anatomical variations which make the standardization process challenging, natural teeth are usually avoided as subjects for research. On the other hand, the presence of enamel and dentine in natural teeth affects the quality of adhesive bonding especially at the marginal area, thus natural teeth were used in this study as they closely resemble the clinical situation. [20,21]

For standardization purpose, all teeth measurements were verified by digital caliper to <10% discrepancy. Moreover, preoperative optical scanning was done for all study samples for digital verification of the preparation by superimposition of both pre and post preparation 3D images.

Marginal gap results for all tested full coverage restorations in this study were within clinically accepted values. The first null hypothesis for this study was rejected as there was statistically significant difference in vertical marginal gap mean values between the two tested finish line designs. Feather edge finish line showed statistically lower gap mean value (29.07± 8.05 μm) than deep chamfer finish line (42.17±2.65 μm). These results agree with Almahdy *et al*, [22] and Comlekoglu *et al,* [23]. They explained these findings could be attributed to the feather margin configuration itself as it forms an acute angle with the tooth providing a shorter distance between the tooth and restoration. El-Eneen *et al*,[24] reported lower marginal gap values for feather edge finish line than chamfer finish line in zirconia lithium silicate crowns but it was statistically non-significant. Schmitz et al, [8] reported that lithium disilicate crowns with feather-edge margins had similar clinical outcomes to other margin designs and materials.

The results for this study disagree with Rizonaki *et al*, [25] who reported that the lowest marginal adaptation was for milled lithium disilicate crowns with feather-edge finish line when compared to both shoulder and chamfer finish lines. This could be attributed to the difference in ceramic materials. Lithium disilicate ceramic blocks used in their study were reported in many literatures to experience chipping during machining and aging due to low stiffness which, can contribute to larger marginal gaps when milled in thin un-defined margin designs. Over-contouring of milled lithium disilicate margins was recommended to overcome margin chipping. [26-29]

In our present study, advanced lithium disilicate strengthened with virgilite (CEREC Tessera) was used for milling of all crowns. More than 700 MPa flexural strength with up to 32% increase in strength than conventional lithium disilicate was claimed by the manufacturer. This might have contributed to high margin adaptation of feather margin after both milling and thermomechanical ageing in comparison to chamfer margin as the risk of chipping was reduced. [11]

Moreover, all restorations were only glazed in porcelain furnace after spray glaze application following manufacturer recommendations, no alterations or surface modifications were done to the restorations. Jurado *et al,* [30] reported that glazing of CEREC Tessera restorations decreases surface roughness which may contribute to less chipping at the marginal area.

Sample in this study were subjected to thermal cycling alongside cyclic loading to provide testing environment that closely resembles the oral conditions.

The results in this study showed that thermomechanical aging significantly increased the vertical marginal gap in both finish line groups. Thus, the second null hypothesis was also rejected.

The deteriorating effect thermomechanical aging on marginal adaptation was frequently reported in literature. Taha *et al*, [31] reported that thermal expansion mismatch between tooth/cement/restoration complex alongside repeated cyclic loading resulted in significant deterioration of ceramic restoration margins. Our results agree with El-Eneen *et al*, [24] they found an increase in marginal gap values in crowns prepared with both feather edge and chamfer margins after thermomechanical aging. Our results also agree with Haggag *et al*, [32] who also reported an increase in vertical marginal gap values for both deep chamfer and feather edge monolithic zirconia crowns. Contrary to our results, Stappert et al, [33] found a non-significant decrease in marginal accuracy after thermomechanical aging. This could be attributed to the difference in ceramic systems they were evaluating from our study. They evaluated pressed lithium disilicate and metal ceramic FPD fabricated from lost wax technique why may contribute to the difference in marginal accuracy results. [34-37]

The results of this study showed non-significant difference in marginal gap values for both feather edge and chamfer groups after thermomechanical aging. These results are in also in agreement with El-Eneen *et al*, [24] who found no significant difference in gap values after thermomechanical aging. This could be attributed to improved gap sealing due to resin cement hygroscopic expansion caused by aging. [38,39] On the other hand, our results disagree with El-Dessouky et al, [40] who reported a significant difference between feather edge and chamfer finish lines after artificial aging.

The results in our study are encouraging regarding the use of advanced lithium disilicate in vertical preparations. Nevertheless, one of the limitations of our study is the in-vitro model. Further clinical studies are needed to assess the periodontal response to this recent ceramic material with vertical preparations. Another limitation of this study is that only one ceramic material was evaluated. Further studies comparing different machinable blocks are required.

CONCLUSIONS

Within the limitations of this study, all tested restorations exhibited marginal gaps within clinically accepted values. Advanced lithium disilicate (CEREC Tessera) monolithic crowns with featheredge margins showed superior margin adaptation to those fabricated with deep chamfer margins and can offer a more conservative solution for reconstruction of severely compromised teeth.

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