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FRACTURE RESISTANCE AND MARGINAL FIT OF ENDOCROWN RESTORATIONS USING THREE DIFFERENT CAD-CAM MATERIALS

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ABSTRACT

INTRODUCTION: Endocrown restorations offer a promising alternative to restore endodontically treated teeth. However, various materials are available without being thoroughly evaluated.
Purpose: The purpose of the study is to evaluate marginal fit and fracture resistance of endocrown restorations using three CAD-CAM materials.
MATERIALS AND METHODS: Eighteen extracted permanent mandibular molars were selected to receive endocrown restoration. Teeth were randomly allocated into three groups based on material type (n=6). (LD): Lithium Disilicate, (FCZ): full contour zirconia, (RNC): resin nanoceramic. All Endocrown restorations were fabricated utilizing CAD-CAM technology. Restorations were adhesively luted to the corresponding prepared teeth and subjected to thermomechanical cycling corresponding to six months of clinical service. Marginal gap was measured before cementation and after cementation and aging using optical microscope. For measuring fracture resistance, samples were loaded till fracture occurs by using Universal Testing Machine. Optical microscope was used to evaluate mode of failure. One-way ANOVA and Tukey's post hoc test were used to analyze fracture resistance, while Two-way ANOVA and Tukey's post hoc test were used to analyze marginal gap.
RESULTS: FCZ had the highest fracture load compared to RNC and LD. Zirconia recorded largest microgaps before cementation.
CONCLUSION: FCZ showed the highest fracture resistance values. LD and RNC ceramics showed fracture resistance with comparable values recommending their use as endocrown restorations. The tested groups showed marginal fit results within the bounds of clinically acceptable parameters. The material type and artificial aging process had a significant impact on the marginal gap.
KEYWORDS: Fracture resistance, Marginal fit, Resin nanoceramics, Zirconia, Lithium disilicate.
RUNNING TITLE: Fracture resistance, marginal fit endocrown using CAD-CAM materials.

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INTRODUCTION

The purpose of root canal treatment is to preserve teeth with affected root canals in order to stop their loss. However, compared to vital teeth, endodontically treated teeth (ETT) are more susceptible to bio-mechanical failure because of the loss of structural strength associated with, cavity preparation, trauma, or caries rather than physical dentin changes or dehydration. Moreover, the survival rate of ETT depends primarily on the remaining tooth structure after RCT (1,2).
To date, no agreement in the literature regarding which type of restoration or material that can properly restore ETT (3). Building a core with or without a post and placing a full coverage crown with sufficient ferrule is considered as the conventional way for restoring ETT. However, preparing a tooth to receive full crown might lead to extensive removal of tooth structure (4,5).
The selection of restoration type may vary based on the amount of tooth structure remains.
However, ceramic restorations, including endocrowns, have recently been developed as alternate choices to restore endodontically treated teeth (6). Bonding of ceramic restorations has become popular because of improvements in adhesive dentistry, as it enhances the fracture resistance and retention of such restorations (7,8). Different materials have been used in literature to fabricate endocrown restorations. Monolithic zirconia, glass ceramics and resin nanoceramics were investigated for strength, fatigue and stress analysis with different cavity designs and different thicknesses at occlusal areas. Increasing modulus of elasticity of the restoring material was found to be beneficial for the durability of bond between tooth and restoration (9). However, monolithic zirconia

results in catastrophic mode of failure in remaining tooth structure when compared to glass ceramics. Moreover, stress distribution was more uniform when resinous materials were used such as resin nanoceramic blocks (10,11).

Most common biological cause of failure in fixed restorations is dental caries. Due to dissolution of dental cements under restorations, marginal gaps could take place resulting in plaque accumulation and eventually dental caries (12). However, machined restorations have acceptable marginal gap, depending on machinability of the material used, exposure to sintering for crystallization cycles and wear of the milling tools. Resin based endocrowns showed larger discrepancies than ceramic based endocrowns in marginal gap (13). High translucent zirconia crowns displayed better marginal fit when compared to lithium disilicate crowns and resin nanoceramic crowns (14).

There is no agreement in the literature that one material is advantageous over another concerning its mechanical behavior or marginal fit. The current study was an attempt to evaluate fracture resistance and marginal fit of endocrown restorations fabricated by using lithium disilicate glass ceramic, full contour zirconia material, and resin nanoceramic before, cementation and after cementation followed by aging. The null hypothesis of this study was that no significant differences would be found between the tested materials according to fracture resistance and marginal fit.

MATERIAL AND METHODS

This research was conducted as in vitro study to evaluate marginal fit and fracture resistance of endocrown restorations using three ceramic CAD-CAM materials LD: e.max CAD Lithium Disilicate (Ivoclar Vivadent, Liechenstein), FCZ: Ceramill Zolid ht plus (Amann Girrbach, Austria), RNC: Gandio blocs (VOCO GmbH, Germany). Natural teeth used in current study were obtained from Department of Oral Surgery, Alexandria University after obtaining ethical approval form institutional review board, Faculty of Dentistry Alexandria University (IRB No. 001056 – IORG 0008839). Collected mandibular molars were used for this research with dimensions as close as possible to average (WHEELER’S Dental Anatomy, Physiology, and Occlusion), free of caries or fracture line, and with mature roots and crowns morphology. Teeth were preserved at 4 degrees Celsius in a 1% chloramine T solution (15).

1. Endodontic protocol

Root canal treatment was performed on all specimens by the same operator to standardize the root canal treatment. Pulp tissue was removed using k-files and working length determined using radiographic periapical x-rays while files inserted in the canals. NiTi rotary files were used for instrumentation (ProTaper, Dentsply, Switzerland). F2 files were used as the master file in the mesial canals, whereas F3 files were used in the distal canals. The irrigation protocol with NaOCl (5.25%) solution after each file for 10 seconds. Protaper paper points was used for drying the canals. Canals were filled with thermoplasticized gutta percha (Dentsply, Switzerland) in sizes F2 and F3 for mesial and distal canals, respectively. Canals were filled with lateral condensation filling technique by using (ADseal, META BIOMED, Korea) root canal sealer. Small carbide bur used to cut the gutta percha 1 mm below each canal orifice, then canals orifices and pulp chamber were sealed using flowable composite resin.

2. Endocrown preparation

The selected mandibular molar roots were embedded in auto polymerized acrylic resin in shape of blocks to a depth (simulated bone level) 2 mm below the CEJ. Crowns were cut horizontally 2-3 mm perpendicular to the tooth long axis using wheel diamond stone (MICRODONT, Brazil). Then pulp chamber preparation done by using inlay bur number 4137 (MICRODONT, Brazil) leaving 3 mm cervical sidewalk for seating of the restoration with 5 mm diameter cylindrical pivot. The height of internal walls from cavity internal margin to the floor of pulp chamber was 5 mm. All undercuts were eliminated either by tooth removal or by adding composite to block out the undercuts in preparations. All line angles internally were smoothened and rounded.

3. Random allocation of teeth randomization method

A total of 18 prepared teeth were allocated randomly according to one of the following groups (n=6): Group LD: e.max CAD Lithium Disilicate, group FCZ: full contour zirconia and group RNC: resin nanoceramic (16). Table 1 lists the composition of the tested materials.

4. Endocrown fabrication

All preparations were scanned by Cerec Omnicam (Sirona Dental Systems, Germany) and checked digitally for proper dimensions for standardization of all specimens then files were exported as STL files to a dental CAD program (Exocad dentalDB). After automatic line detection for preparation, endocrown restorations were created by using the same library for all three groups with 2 mm thick material at the central groove and 2.5 mm at level of cusp tips. (Figure 1) All designs were imported into CAM program for nesting in each material according to grouping.

5. Cementation of endocrown restoration

The manufacturer's guidelines were followed while cementing each group of endocrown restorations, For the LD group, hydrofluoric acid gel (BISCO porcelain etchant 9.5%) was used to etch the intaglio surface of LD endocrowns for 20 seconds, then rinsed for 60 seconds and dried for 30 seconds with oil free air, ceramic primer (porcelain primer, BISCO, U.S.A) was applied to the intaglio surface of LD endocrowns for 60 seconds then dried with oil free air. FCZ group was air borne abraded with 50 µm AL_2O_3 aluminum oxide particles for 10 sec, sand was removed using alcohol then dried with oil free air. zirconia primer (Z-prime plus, BISCO, U.S.A) was applied to the intaglio surface of FCZ endocrowns for 60 seconds then dried with oil free air. For RNC group the intaglio surface was air borne abraded with 25 µm aluminum oxide particles, cleaned with ultrasonic cleaner and dried with oil free air, then silane coupling agent (porcelain primer, BISCO, U.S.A) was applied to the intaglio surface of RNC endocrowns for 60 seconds then dried with oil free air. All Prepared teeth were etched for 15 seconds using 37% phosphoric acid etching gel (SELECT HV ETHC, BISCO, USA), rinsed for 10 seconds, and dried with oil-free air. Photopolymerized adhesive was applied to all teeth, then air thinning and photopolymerization (All bond universal, BISCO, U.S.A). Dual cure resin cement (Duo-link universal, BISCO, U.S.A) was applied to the fitting surface of the restoration and on prepared teeth using auto mixing tip, then restoration loaded with cement was gently seated on its corresponding prepared tooth, initially with finger pressure followed by application of a constant static load of 5kg (17) by a specially designed device to ensure seating of the restoration for 60 seconds before photopolymerization. Then specimens were tack cured for 2 seconds and excess cement after that removed with scalpel, followed by completion of light curing procedure for 20 seconds at each surface. Finally, tooth-restoration interface was polished using fine diamond point.

6. Thermomechanical cycling

Samples were subjected to 600 thermal cycles, while load cycling involves subjecting the specimens to 120,000 mechanical loading cycles of 50 N in each group with indenter size of 6 mm ball shape and frequency of 2.0 Hz. These aging procedures were intended to simulate six months of clinical service (18).

7. Assessment of Marginal Gap

The tested specimens were captured from three points buccal and three points lingual at 8X magnification before cementation and after aging using a stereomicroscope (Olympus SZ1145 Trinocular Stereomicroscope). To achieve complete seating, a specially designed metal device (Figure 2) was used for seating of each endocrown restoration on its corresponding prepared tooth. Images were imported to computer software (Image J.JS V0.5.6) for analysis (Figure 3). The data were tabulated for statistical analysis, and the mean of marginal gap in µm for all specimens were calculated and tabulated.

8.Fracture resistance

The specimens were attached to the lower part of the universal testing machine. An 8mm diameter metal sphere indenter loaded on the center of occlusal surface of each tooth until fracture occurred. The machine testing speed was 1mm/min, and the breaking force was recorded in newtons (N). Fractured parts were collected then inspected visually and under stereomicroscope (Olympus SZ1145 Trinocular Stereomicroscope) at 3x to determine failure mode according to the following: type I: endocrown restoration fracture only without displacement (reparable), type II: debonding of endocrown restoration without fracture (reparable), type III: facture of endocrown restoration with displacement (reparable), type IV: fracture of endocrown restoration and tooth (irreparable) (13).

Statistical analysis

The Shapiro Wilk test was used to determine the normality of the data, Q-Q plots and descriptives. Normality was assumed for fracture resistance and marginal gap, however, percent change in marginal gap was not normally distributed. According to the following formula percent change in marginal gap was calculated: [(Values after aging – Values before aging) / Values before aging] x 100. To assess fracture resistance between groups, a one-way ANOVA was used, followed by a Tukey's post hoc test. Two-way ANOVA and Tukey's post hoc test with Bonferroni correction were used to investigate the effect of material type and thermocycling on marginal gap. To compare percent change between groups, the Kruskal Wallis test was used. All tests were two-tailed and significance level was set p value≤0.05. Data were analyzed using statistical package for social sciences (SPSS) program (IBM SPSS version 23, NY, USA).

RESULTS

The study evaluated the fracture resistance and marginal fit of endocrown restorations fabricated from three different ceramic materials (LD): Lithium disilicate, (FCZ): Full contour zirconia, (RNC): Resin nanoceramic.

Fracture resistance results

The mean fracture resistance load values in (Newton) and standard deviation are presented in table (2) and Figure (5). The highest fracture resistance was associated with FCZ group (2953.51 ± 387.85) followed by LD group (1966.91 ± 481.02) followed by RNC group (1726.75 ± 283.58) which showed the lowest values of fracture resistance load. One-way ANOVA findings showed a statistically significant difference in fracture resistance between the tested groups (P<0.0001*).

Pairwise comparison showed significant difference when comparing FCZ group to RNC group (P<0.0001*) and FCZ group to LD group (P=0.005*), on contrary, there was no significant difference between the RNC and LD groups.

Failure mode analysis results

Failure mode results of the tested materials showed that the three tested groups FCZ and LD and RNC had catastrophic mode of failure (irreparable fracture) as presented in figure (4). Only one specimen did not undergo fracture in FCZ group.

Marginal gap results

Results of marginal gap before cementation and after cementation and aging measured in (µm) are presented in table (3) and Figure (6). The overall estimate of marginal gap was the highest in FCZ group (44.50 µm), followed by LD group (39.21 µm) and the least in RNC group (36.13 µm). The material type (P= 0.016*) and thermomechanical cycling (P= 0.010*) had a significant effect on marginal gap with partial eta squared 0.118 and 0.068 respectively. Whereas there was no significant effect of the interaction between the two factors (P= 0.275). The only significant difference among groups was between FCZ and RNC before cementation
(P= 0.017*). RNC group had significant difference in the marginal gap before cementation and after aging (P=0.002*).

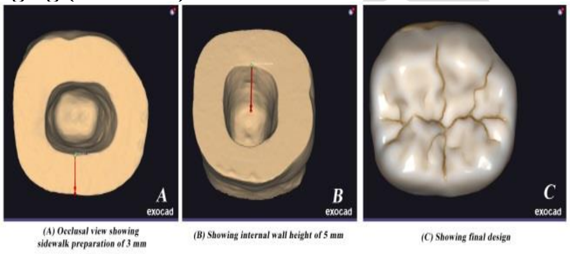


Figure (1): (A) Occlusal view showing sidewalk preparation of 3mm. (B) Showing internal wall height of 5 mm. (C) Showing final design.

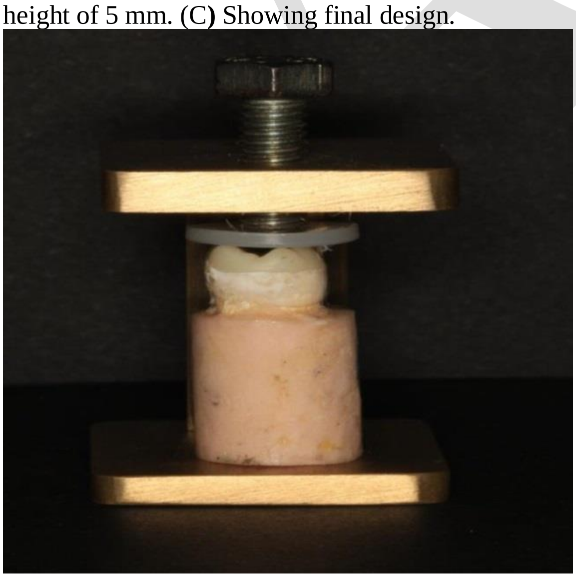


Figure (2): Showing stabilization device fixing the restoration against its corresponding preparation to be examined under optical microscope.

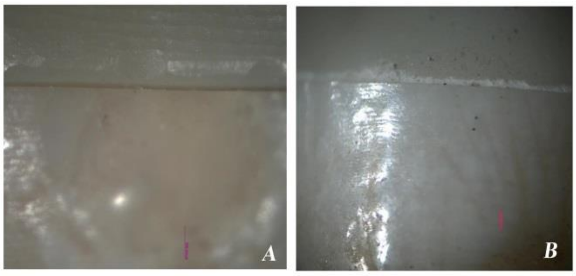


Figure (3): Showing marginal gap measurement before cementation (A) and after aging (B)

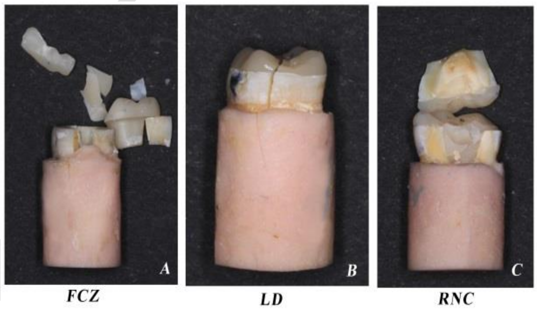
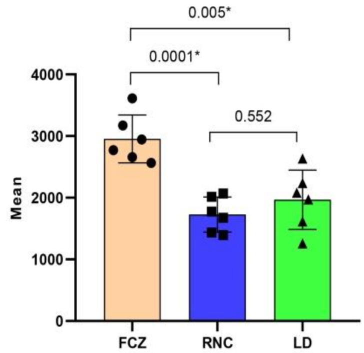
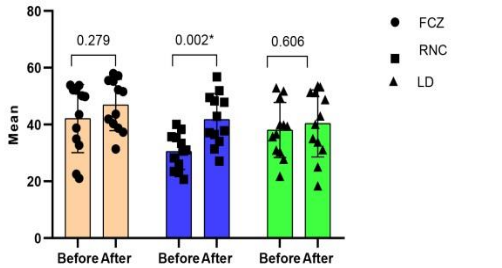


Figure (4): Showing example of fractured specimens in each group (A) FCZ (B) LD (C) RNC.



Abbreviations: LD: Lithium Disilicate, FCZ: Full contour zirconia, RNC: Resin nanoceramic.

Figure (5): Mean and SD of fracture resistance among study groups.



Abbreviations: LD: Lithium Disilicate, FCZ: Full contour zirconia, RNC: Resin nanoceramic

Figure (6): Mean and SD of marginal gap among study group

Table (1): Materials used in the study (material, manufacturer, ceramic type, chemical composition, and Lot number)

Group	Material	Manufacture	Ceramic type	Chemical composition	Lot number
LD	e.max CAD	Ivoclar Vivadent, United States	lithium disilicate glass ceramic	SiO_2, Li_2O, K_2O, P_2O_5, ZrO_2, ZnO, Al_2O_3, MgO, coloring oxides.	Y52 153
FCZ	Ceramill zolid ht +	Amann Girrbach, koblach, Austria	Yettria partially stabilized zirconia polycrystals	ZrO_2 + HfO_2 + Y_2O_3: $\geq$ 99.0,Y_2O_3: 6,7 - 7,2,HfO_2: $\leq$ 5,Al_2O_3: $\leq$0.5,Other oxides: $\leq$ 1	2005 001
RNC	Grandio blocs	VOCO GmbH, Cuxhaven , Germany	Nano hybrid composite	86% w/w inorganic filler in a polymeric matrix	2051 342

Abbreviations: LD: Lithium Disilicate, FCZ: Full contour zirconia, RNC: Resin nanoceramic

Table (2): Comparison of fracture resistance among FCZ, RNC, and LD groups.

	FCZ (n=6)	**RNC (n=6)**	**LD (n=6)**	**F test (*P* value)**
Mean ± SD	2953.51 ± 387.85[a]	1726.75 ± 283.58[b]	1966.91 ± 481.02[b]	16.459 (<0.0001*

*Statistically significant difference at p value ≤0.05, different superscript lowercase letters denote statistical significance difference between groups.
Abbreviations: LD: Lithium Disilicate, FCZ: Full contour zirconia, RNC: Resin nanoceramic.

Table (3): Comparison of marginal gap before and after thermomechanical cycling among FCZ, LD, and RNC groups.

		FCZ (n=6)	RNC (n=6)	LD (n=6)
Before	Mean ± SD	42.09 ± 11.99	30.49 ± 6.32	38.05 ± 9.71
After	Mean ± SD	46.91 ± 9.06	41.76 ± 9.13	40.36 ± 11.80
P value		0.279	0.002*	0.606

*Statistically significant difference at p value ≤0.05
Abbreviations: LD: Lithium Disilicate, FCZ: Full contour zirconia, RNC: Resin nanoceramic.

DISCUSSION

The purpose of this study was to evaluate fracture resistance and marginal fit of endocrown restorations using three different ceramic CAD-CAM materials. While using natural teeth in the study may have introduced some variability due to challenges in standardization, but in the presence of enamel and dentin it reflects the clinical environment more accurately, and the superiority of natural teeth over metallic and resinous specimens in term of biomechanics and adhesion (18). Using of CAD/CAM ceramic materials for endocrown restoration were evaluated in this study because they have the advantage of chair time minimizing, achieving a better acceptable marginal fit, appropriate esthetics, and strength of restoration. Simulating aging is a crucial component of in vitro study, as the repeated stresses of mastication can cause ceramic materials to develop small cracks over time. all samples in this study were subjected to thermal cycling and mechanical loading to simulate 6 months of clinical service (19).

A standardized cementation protocol to all specimens was performed according to manufacturer's instructions. **Borges et al,** (20) found that no statistically significant difference in ceramic crowns regarding marginal gap before or after cementation when using resin or resin modified glass ionomer cements. In the current study, no differences in marginal gaps were expected due to cementation protocol and hence, no evaluation was done immediately after cementation.

In literature, assessment of the marginal gap can be performed either by invasive technique through cross sectioning of the specimen and internal viewing or noninvasive technique by viewing specimen from external surface. Noninvasive direct viewing technique was used for measuring the marginal gap under stereomicroscope from external surface of specimen by the same operator to avoid any possible errors. This method considered less invasive, less time consuming, and cost-effective. This method has some limitations as the points measured are hardly distinguished and the observer angle cannot be standardized for all specimens during measuring procedures (21).

The fracture resistance analysis results revealed a statistically significant effect of material type on fracture resistance. Consequently, the first null hypothesis was rejected. FCZ has high crystal structure stability, this crystal structure is similar to that of diamond, which gives it its hardness and high resistance to fracture. Additionally, the unique transformation toughening mechanism, which allows it to inhibit crack propagation and resist fracture. When zirconia is subjected to stress, the crystal structure undergoes a phase transformation from s tetragonal phase to a monoclinic phase. Volume expansion results due to this this transformation, which produces compressive stresses around the tip of crack and increases its toughness and resistance to crack propagation.

The composition of RNC allows it to have an elasticity modulus (18.28 GPa) comparable to tooth dentin (5.5-19.3 GPa). and they distribute stress similar to dentin under loading. While stiff glass ceramic materials as lithium disilicate that have different modulus of elasticity, can produce stress concentrations at specific areas and catastrophic mode of failure may occur (15). The outcomes obtained from this study agree with those of a systematic review that compared fracture resistance of LD and RNC endocrowns under loading and determined that RNC endocrowns had comparable fracture resistance values to LD endocrowns (22).

The incorporation of a resin matrix within RNC blocks may enhance adhesion to resin composite luting agents, thereby promoting a more homogeneous distribution of stress. Furthermore, it has been shown that the application of adhesive cement may balance the fracture resistance of high strength restorations to a level equivalent to that of low strength restorations (23). The average fracture loads in all groups exceeded the maximum masticatory forces reported in the literature.

All specimens were subjected to both thermal cycling and mechanical loading to simulate clinical service. The literature has previously reported on the deteriorating impact of thermomechanical aging on ceramics (24). Thermal cycling produce stresses at the adhesive interface, caused by variations in the coefficient of thermal expansion (CTE) between the restoration and the tooth. (25,26). The composition of restorative materials is found to influence this factor, where a larger difference in the CTE between tooth structure and restorative material can generate excessive stresses during temperature fluctuations. This may cause microcracks that could propagate along the bonded interface, resulting in the formation of microgaps, that might grow larger with augmented mechanical loading.

The second null hypothesis was rejected as a result of the findings of this study because tested materials and thermomechanical cycling had statistically significant effect on marginal gap of one group. In FCZ group Marginal gap was larger than RNC before cementation. This finding could be explained by difference in manufacturing process, that include different machining tools, milling strategy and crystallization or sintering cycles. In RNC group, thermomechanical aging adversely affected the marginal gap, this is supported by research conducted by **Eldamanhory et al**, who found that RNC endocrown restorations showed a greater degree of marginal gap when compared to other ceramics (15). This might be related to the greater coefficient of thermal expansion (CTE) of these resinous materials, which are composed of 80% particles of nanoceramic and 20% of resin matrix. As a result of this thermal expansion, RNC restorations can increase the impact of thermocycling on the marginal fit, leading to an increase in marginal gap. While in this study FCZ and LD had no differences in marginal gaps before and after cementation.

On contrary, difference in CTE between enamel and both LD and zirconia is large, predisposing to marginal gaps especially after thermal cycling. Zirconia can be minimally affected by stresses induced by mechanical loading as it has high fracture strength, whereas RNC has a lower fracture load and could be adversely affected by a low stress mechanical loading. Despite the increase in marginal gaps after aging, it is important to note that all marginal gap measurements in this the current study were within clinically acceptable standards of 120 µm, as established by McLean and von Fraunhofer. Values of the current study were below 50 µm of mean gap.

The result of this study supports findings of **Krejci et al**, (27) who found a significant adverse effect of thermal cycling on the marginal integrity of adhesive luted restorations. Similarly, **Hung et al**, (28) found that both thermal and mechanical cycling had a significant negative impact on the marginal fit of crowns. However, aging has no adverse effect on the marginal fit of ceramic crown restorations, as reported by **Beschnidt and Strub**, (29).

The use of a single adhesive and luting cement system was a limitation of the current study. Using various systems might result in different outcomes. Moreover, variables such as cement film thickness, bond strength data, preparation design were not assessed. It should be noted that the use of a solitary monotonic load to induce failure may not accurately reflect actual clinical conditions. Consequently, further research is required to investigate the influence of these factors on mechanical behavior of ceramic restorations as endocrowns.

CONCLUSION

According to the results of this study:

1- FCZ, LD and RNC ceramic materials showed the fracture loads surpass masticatory forces reported in the literature, FZC group provided the highest, followed by LD group and RNC group.

2- All tested groups showed marginal fit results within clinically acceptable parameters. The overall estimate of the marginal gap among all groups, FCZ had the highest value (44.50 µm), followed by LD (39.20 µm) and the least value in RNC group (36.13 µm). The type of material type and thermomechanical cycling were found to have an effect on the marginal gap. However, the interaction between these two factors was not found to be significant (P= 0.275).

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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