International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)
Journal Home page: www.iscientific.org/Journal.html

In-vitro comparison of marginal gap and fracture resistance of prefabricated zirconia crowns and three dimensional- printed endocrowns for restoration of pulpotomized primary molars

*Lamiaa Hussein Abbas *[1], Mariem Osama Wassel[2], Islam Tarek Hassan[3], Ayman Galal El-Dimeery[4], Reham Khaled ElGhazawy[5]*

[1]*Department of pediatric dentistry and dental public health, faculty of dentistry, Ain Shams university*

[2]*Department of pediatric dentistry and dental public health, faculty of dentistry, Ain Shams university*

[3]*Orthodontic department, faculty of dentistry, Ain Shams university*

[4]*Lecturer of fixed prosthodontics, Misr international university*

[5]*Department of pediatric dentistry and dental public health, faculty of dentistry, Ain Shams university*

Abstract

To compare the marginal gap and fracture resistance of 3D-printed endocrowns and prefabricated zirconia crowns for the restoration of pulpotomized primary molars. There was a statistically significant difference in the marginal gap values between prefabricated zirconia crowns (0.65±0.21) and three dimensional (3D)-printed endocrowns (0.12±0.03) groups with prefabricated zirconia crowns having significantly higher values than endocrowns. There was no significant difference between both groups regarding fracture resistance (p=0.527). Prefabricated zirconia crowns had a statistically significant higher marginal gap values than 3D-printed endocrowns. The marginal gap for prefabricated zirconia crowns is high and searching for alternatives is recommended.

Keywords: Pulp therapy, digital dentistry, additive manufacturing, deciduous teeth.

Full length article **Corresponding Author*, e-mail: dr.lamya@dent.asu.edu.eg

1. Introduction

Stainless steel crowns (SSCs) are the gold standard for restoring pulpotomized primary molars. However, their metallic appearance is unacceptable [1]. Recently, prefabricated zirconia crowns (PZRCs) have shown a great advantage as a replacement for SSCs having high clinical and esthetic performance [2]. However, there are some clinical limitations and disadvantages for PZRCs as they require aggressive tooth reduction and are expensive[3]. Recently, digital dentistry has rapidly progressed , especially since the emergence of computer-aided design/ computer-aided manufacturing (CAD/CAM) systems [4]. The most recent wave of technological development in digital dentistry is three dimensional (3D) printing [5]. 3D-Printed crowns and bridges have been shown to serve as durable provisional and long-term restoration [6].

With the emergence of adhesive dentistry, more conservative approaches have been considered. One of these strategies is the use of endocrowns (ECs). Endocrowns are monolithic adhesive ceramic restorations with a special preparation design [7]. Their retention is gained macro-mechanically by friction with the pulpal walls, and micromechanically through adhesive cementation. Ongoing research on biomimetic materials with physical and mechanical properties similar to those of natural tooth tissues has introduced a new generation of nanofilled hybrid composite restorative materials [8]. Primary teeth undergoing pulpotomy require full or partial coverage restoration to strengthen the remaining tooth structure and avoid cervical tooth fracture [9]. A good fit is essential to guarantee the mechanical stability, durability, and health of surrounding soft tissues. Insufficient adaptability can lead to dental plaque accumulation, microleakage of adhesive, discoloration of edges, and lack of esthetics, tooth sensitivity, dental caries, and periodontal disease [10]. Few studies evaluated the marginal fit of prefabricated zirconia crowns[11, 12]. Fracture resistance is one of the parameters to determine the survival of the restoration and its ability to withstand occlusal forces. There are few studies comparing the fracture resistance of ECs with prefabricated ZRCs for restoration of pulpally treated primary molars [13,14]. Other studies [15,16] evaluated the fracture resistance of 3D printed restorations in primary teeth. The null hypothesis was that there is no difference in the marginal gap or the fracture resistance of 3D-printed microfilled hybrid composite endocrowns and zirconia crowns in restoring pulpotomized primary molars.

2. Materials and methods

2.1 Sample size estimation

A power analysis was designed to have adequate power to apply a 2-sided statistical test of the null hypothesis that there is no difference between 3D-printed microfilled hybrid composite endocrowns and prefabricated zirconia crowns for restoring pulpally-treated primary molars regarding marginal gap and fracture resistance. An effect size (d) of (1.32) was calculated based on the results of previous authors[17]. and by adopting an alpha (α) level of 0.05 (5%), a beta (β) level of 0.20 (20%) i.e power=80%, and using the calculated effect size (d=1.32); the predicted sample size (n) was found to be a total of (20) samples. i.e. (10) for each group. Sample size calculation was performed using G*Power version 3.1.9.2 [18].

2.2 Ethical considerations

Ethical approval number (FDASU-ReclD072021) was obtained from the Institutional Research Ethical Committee (FDASU-REC). Parents agreed on using their children's extracted teeth for research purposes. The study followed the principles of the Declaration of Helsinki.

2.3 Study setting

Extracted teeth were collected from the outpatient clinic, pediatric dentistry and public health department. Marginal gap analysis and fracture resistance testing were done at Biomaterials department.

2.4 Teeth Selection

Thirty mandibular second primary molars were collected. The teeth were extracted for orthodontic reasons or due to the presence of large radiolucency approaching the permanent successors. For standardization, the teeth were selected to be with an average bucco-lingual dimension of (6.5 ± 1 mm) and mesio-distal dimension (9.5 ±1 mm) measured using a digital caliper. (fig. 1)
Twenty teeth were then selected according to the following:

2.4 1 Inclusion criteria

1. Sound or decayed second primary molars having at least three intact axial walls.
2. At least one-third of the root was still intact, with an intact floor of the pulp chamber.

2.4.2 Exclusion criteria

1.Previous pulp therapy or restorative procedure
2.Developmental defects

2.5 Procedures

All soft tissue debris were removed by a hand scaler and teeth were disinfected with 10% thymol and stored in distilled water at room temperature until usage for a maximum of one month. Pulpotomy was performed in all molars as previously described. The molars were randomly divided into two groups:
Group A : received prefabricated zirconia crowns. Tooth filling and preparation were done as previously described.
Group B : received 3D-printed endocrowns. Tooth filling and preparation were done as previously described.
Steps for the in-vitro study are shown in figure (2).

2.6 Marginal gap analysis

Measurements of the cervical horizontal marginal discrepancies were done before cementation (fig. 3,4). The specimens were embedded in rubber base for stabilization. For each specimen, three or four points along the margins for each axial surface were captured using Dino lite digital microscope (Dino-Lite digital microscope, Taiwan) (figure 61) at 50 X magnification. Then the marginal gap was measured using a software (Dino capture 2.0 version 1.5.43, Taiwan). The average marginal gap for each specimen was calculated. The gap distance was measured in millimeters. (fig. 5-11)). Restorations were then cemented with packable glass ionomer (Equia Fil, GC, Japan) for zirconia crowns and self-adhesive resin cement for endocrowns as previously described.

2.7 Fracture Resistance test

The specimens were embedded perpendicularly in Polyvinyl chloride (PVC) cylinders with the occlusal surface parallel to the ground using self-cure acrylic resin extending 2mm below the cemento-enamel junction. To simulate the periodontal ligaments, a single layer of teflon tape was wrapped around the roots of the teeth before being imbedded in the acrylic resin [14]. (fig. 12,13). The test was done three days post-cementation to allow for maximum strength of the glass ionomer cement. An axial loading through the functional cusp was applied using a stainless steel round ended load applicator attached to the upper part of the universal testing machine (Instron 3365, Norwood, MA, USA) at cross head speed of 1 mm/min. Tin foil was placed between the specimen and the load applicator to achieve homogenous stress distribution. Specimens were loaded till failure (figures 14,15) and the fracture resistance values were calculated using computer software (Instron®Bluehill Lite Software). The load required to fracture was recorded in Newton (N).

3. Results

3.1 Marginal gap

Inter and intragroup, mean and standard deviation values for marginal gap (mm) are presented in figure 16 . There was a statistically significant difference in the marginal gap values between ZRCs (0.65±0.21) and ECs (0.12±0.03) groups with ZRCs having significantly higher values than ECs.

3.2 Fracture resistance

Inter and intragroup, mean and standard deviation values for maximum load (N) are presented in figure 17. There was no significant difference between both groups regarding fracture resistance (p=0.527).

4. Discussion

Human teeth were selected to mimic the clinical situation where the tooth architecture and morphology would be more accurate than artificial dies. Moreover, the monoblock action of the endocrowns depends on bonding to enamel and dentin which consequently affects the fracture resistance of the specimens [19]. The results of the present study showed no significant difference between zirconia crown and endocrown groups in fracture resistance. The mean and standard deviation for the maximum load value for zirconia crown was 1342.33±311.49, while for endocrown was 1269.64±172.27. Both values are much higher than the physiologic maximal occlusal force which may reach (500 N) depending on facial morphology and age [20]. Owais et al[21] found that the maximum occlusal bite force on average for the different dentition stages were 176 N in early primary stage, 240 N in late primary stage, 289 N in early mixed stage, 433 N in late mixed stage , and 527 N in the permanent dentition stage. Therefore, it can be assumed that all the tested specimens could withstand the maximum intraoral posterior masticatory forces. To the best of our knowledge, no previous studies compared fracture resistance of 3D printed resin endocrowns to ZRCs in primary teeth. However, few studies[14, 13,22,16,15] compared ceramic or composite endocrowns to zirconia crowns, the results of which can be compared to the results of our study. In contrast to our results, El Makawi & Khattab [14] found that prefabricated ZRCs showed higher fracture resistance than LS2 pressed endocrowns. Nevertheless, the mean and standard deviation for the maximum load value for zirconia crown in the previous study was 1420.893 ± 308.39 N which is very close to the values obtained in our study. On the other hand, LS2 endocrown showed a mean and standard deviation of 854.427±130.52 N, a value much lower than the value obtained in our study for 3D printed endocrowns. This may be attributed to the difference in the materials used for endocrown fabrication. Unlike ceramics, hybrid composites have a modulus of elasticity similar to that of the tooth structure thus having a biomimetic effect resulting in better stress distribution [8]. Composites are resilient; thus, part of the applied force is dissipated in composite deformation before fracture. Sabbah et al[13]also found prefabricated ZRCs to have a significantly higher mean fracture resistance (1229±192.6) compared to primary molars restored with nano-ceramic composite ECs (845.4 ±51.5). Again, the mean and standard deviation values for ZRCs were close to those in our study while those for ECs were much lower.

This conflict in results may be due to the use of different techniques for fabrication of composite ECs. In the study by Sabbah et al., [13], direct-indirect composite technique was used for fabrication of ECs. This technique is operator dependent and inevitably results in voids in the restoration because of the incrementation process. On the other hand, 3D-printing is operator independent where the layering of the restoration is digitally controlled and thus, is more predictable and more reliable. The results of the present study is in line with those of Kim et al.,[16] who compared the fracture resistance of 3D-printed crown using NextDent C&B MFH, and prefabricated zirconia crown (NuSmile) in primary molars. The researchers found no significant difference in the fracture resistance of 3D printed resin crowns compared to that of prefabricated zirconia crowns. Al-Halabi et al[15] compared the fracture resistance of 3D printed resin crowns (GC Temp PRINT; Tokyo, Japan), PMMA crowns milled by CAD\CAM and direct composite celluloid crowns in primary molars. A significant difference in fracture resistance among the three experimental groups was found, with 3D printable crowns and CAD\CAM fabricated crowns showing a significantly higher fracture resistance force compared with direct celluloid composite crowns. The indirect techniques (CAD\CAM milling and 3D printer) showed comparable score to that of prefabricated ZRCs and 3D-printed ECs in the present study. This may further demonstrate the superiority of digital indirect techniques.

Yehia et al.,[22] compared the fracture resistance of three different endocrown materials in pulpotomized primary molars; CAD/CAM Milled Hybrid Ceramics(VitaEnamic),CAD/CAM Milled Poly-methyl methacrylate (PMMA), and indirect Nano hybrid Composite resin (Filtek Z250). All types of endocrowns demonstrated comparable fracture resistance mean values with no statistically significant difference between them. However, the indirect composite endocrown group scored the least values. The fracture resistance values obtained were very close to the values obtained for prefabricated ZRCs and 3D-printed ECs in the present study. In light of these previous results, it may be concluded that the high values for fracture resistance of ECs in our study may be attributed to the material used and the additive manufacturing technology. The published literature lacks enough information about marginal gap in prefabricated ZRCs. The results of the current study were in line with the results of Mohen et al[12] who carried out an in-vitro study to evaluate the marginal quality of resin composite and hybrid ceramic crowns (CAD/CAM) compared with metal and prefabricated ZRCs. Luting gap analysis showed that ZRCs had the largest width. Significantly wider marginal gaps were observed for both the composite crowns and the ZRCs. The high marginal gap of ZRCs is not surprising as ZRCs are performed crowns; consequently, a clinician selects the crown size which is deemed most appropriate to the prepared tooth. Additionally, the passive fit of ZRCs requires more aggressive preparation with elimination of all undercuts[3]. The results of the present study were also in line with the results of Salman et al.,[11] who assessed the external marginal adaptation of the prefabricated ZRCs (Nusmile) after cementation with self-adhesive resin cement using 20x stereomicroscope magnification .The authors concluded that the external marginal for ZRCs is high and searching for alternatives is required. On the other hand, Al-Haj Ali et al.,[23] assessed and compared the marginal and internal fit of SSCs with those of PVSSCs and ZRCs using different luting cements. A clear marginal and internal gap was observed in all the tested crowns. However, no significant difference was observed between ZRCs, PVSSCs, and SSCs regardless of the luting cement used. The marginal gap width mean for zirconia crown had much lower values than that recorded in our study (0.17±0.09). This conflict in results may be due to the different techniques used to measure the marginal gap.

Fig1: Measuring tooth dimensions with a digital caliper, a) mesiodistal, b) buccolingual.

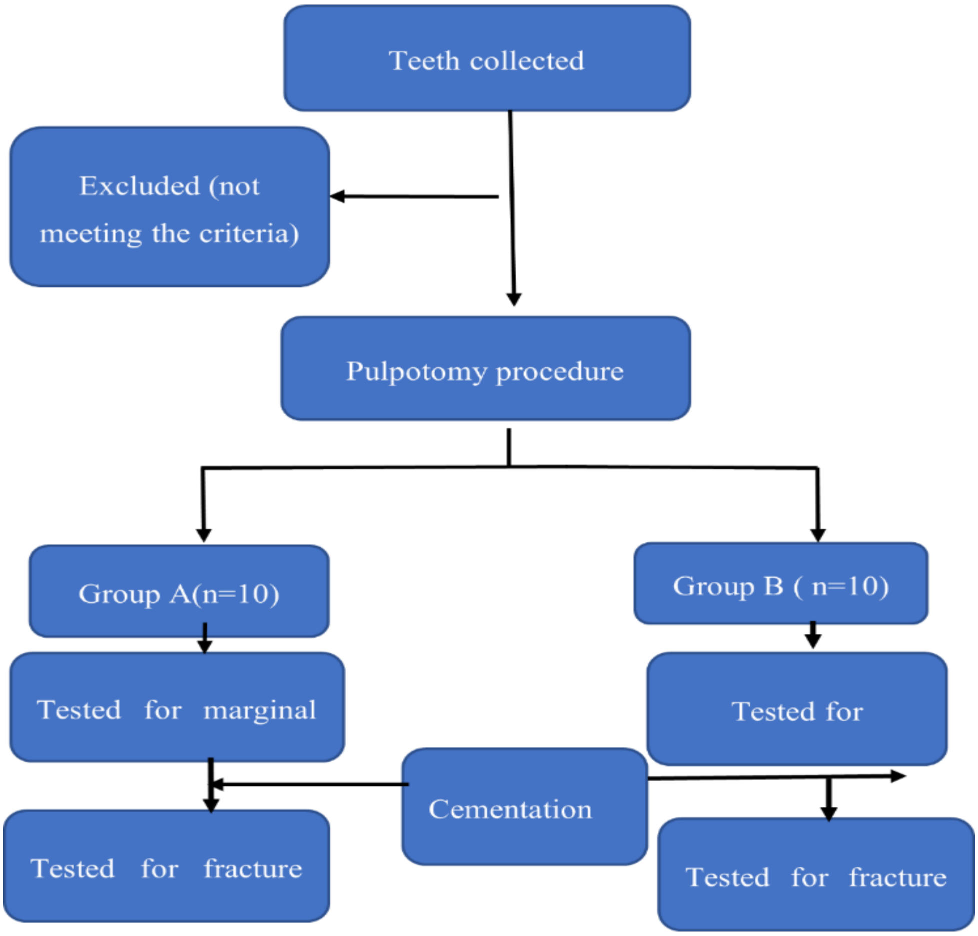

Figure 2: Steps for the in-vitro study

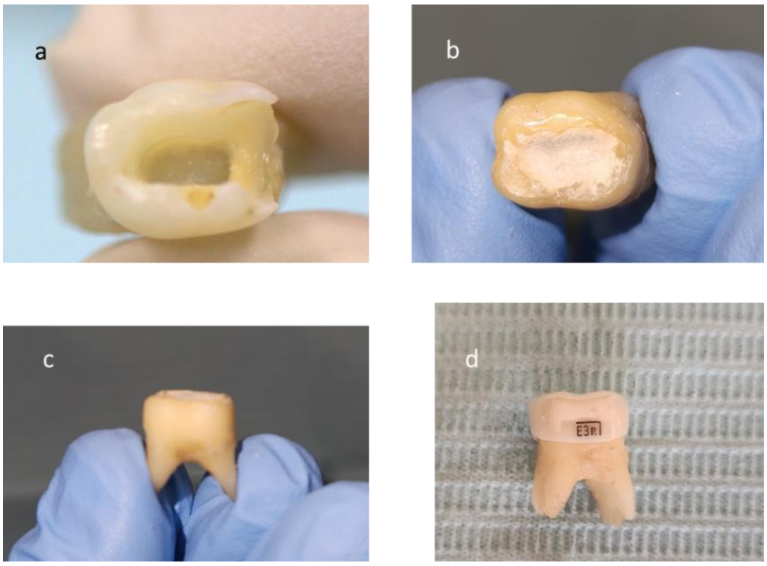

Fig 3: Procedures for group A before marginal gap analysis: a) pulpotomy, b) IRM, c) tooth reduction for zirconia crown, d) zirconia crown fitted before cementation.

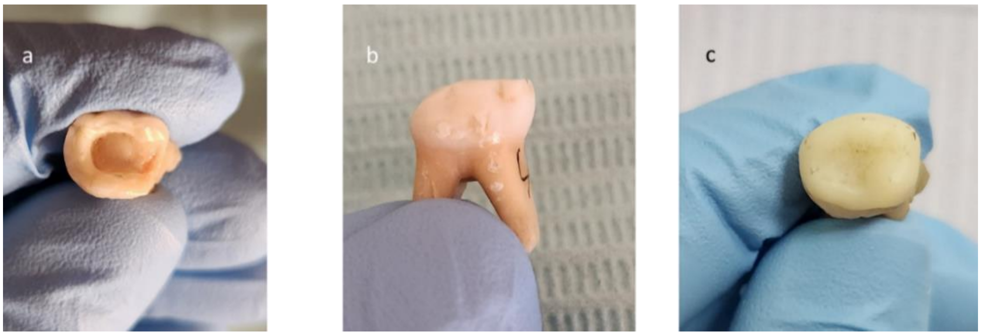

Fig 4: Procedures for group B before marginal gap analysis, a) pulpotomy and tooth filling, b) Endocrown preparation, C) Endocrown seating.

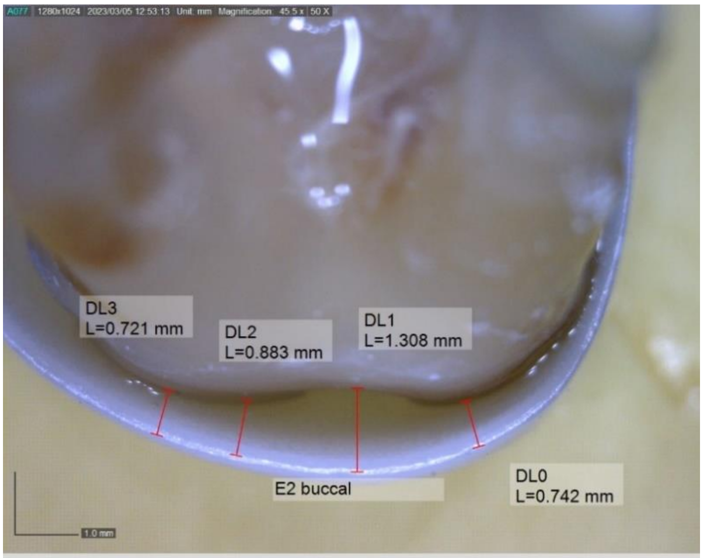

Fig 5: Digital microscope image to measure marginal gap for a specimen in group A: Buccal surface.

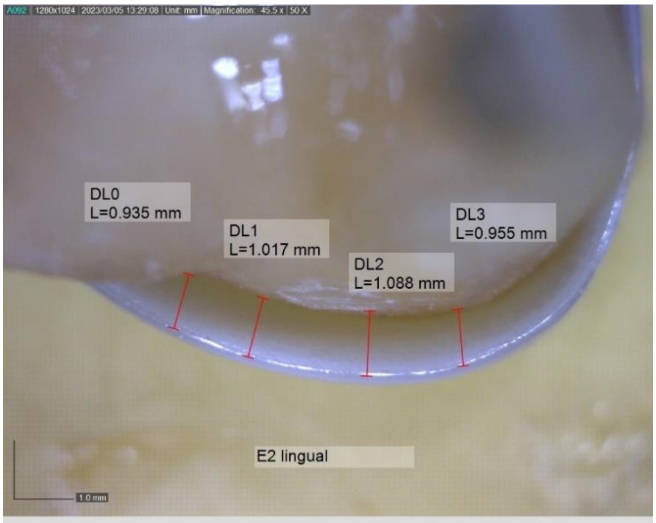

Fig 6: Digital microscope image to measure marginal gap for a specimen in group A: Lingual surface.

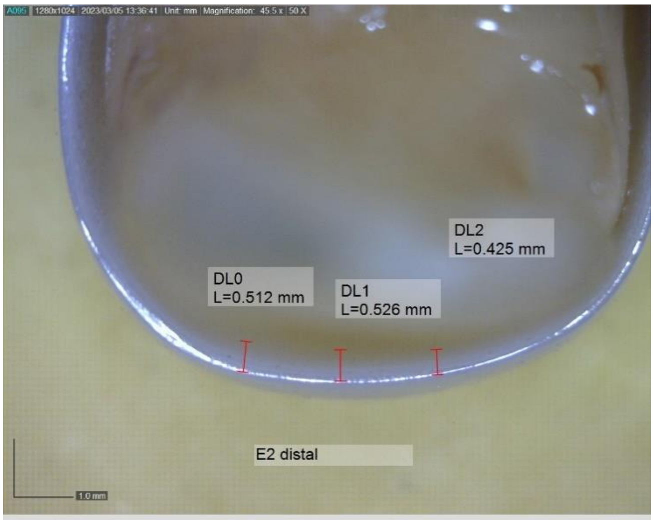

Fig 7: Digital microscope image to measure marginal gap for a specimen in group A: Distal surface.

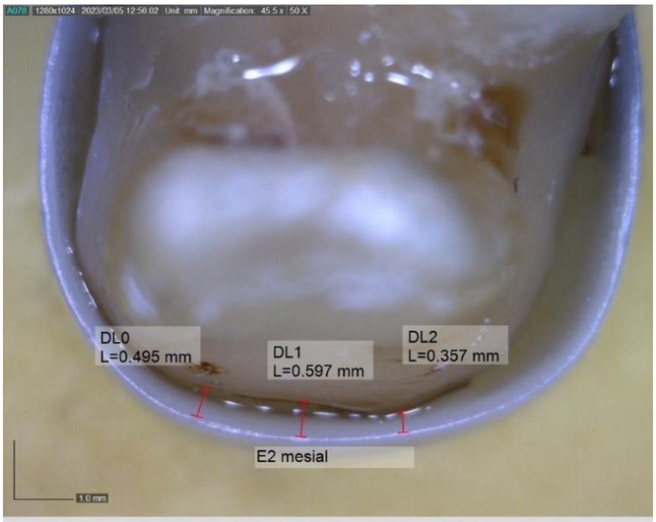

Fig 8: Digital microscope image to measure marginal gap for a specimen in group A: Mesial surface.

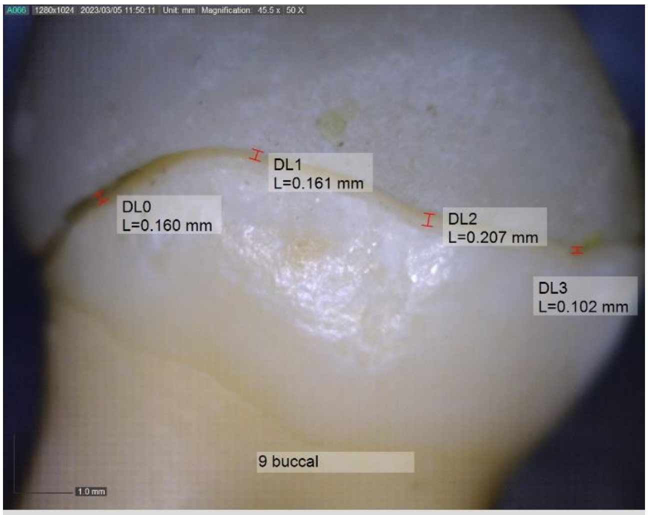

Fig 9: Digital microscope image to measure marginal gap for a specimen in group B: Buccal surface.

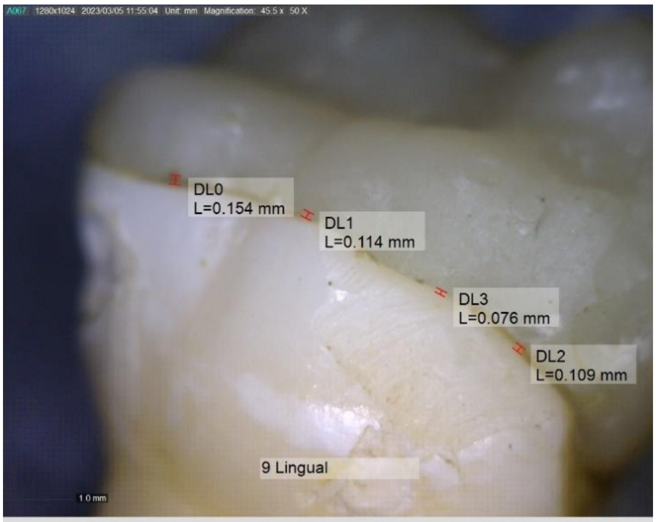

Fig 10: Digital microscope image to measure marginal gap for a specimen in group B: Lingual surface.

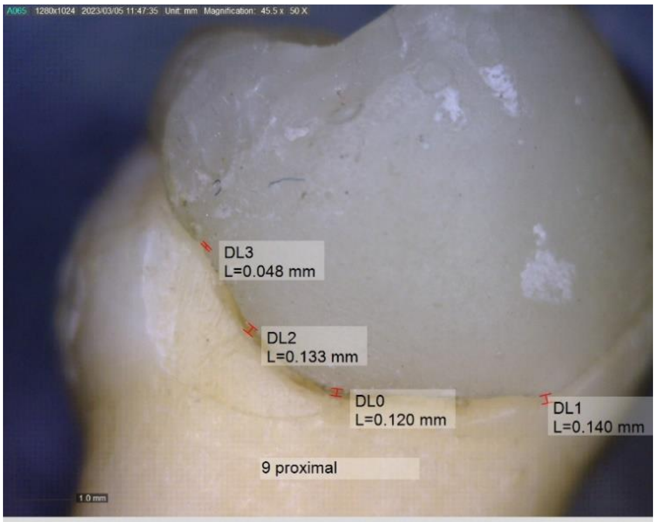

Fig 11: Digital microscope image to measure marginal gap for a specimen in group B: Distal surface.

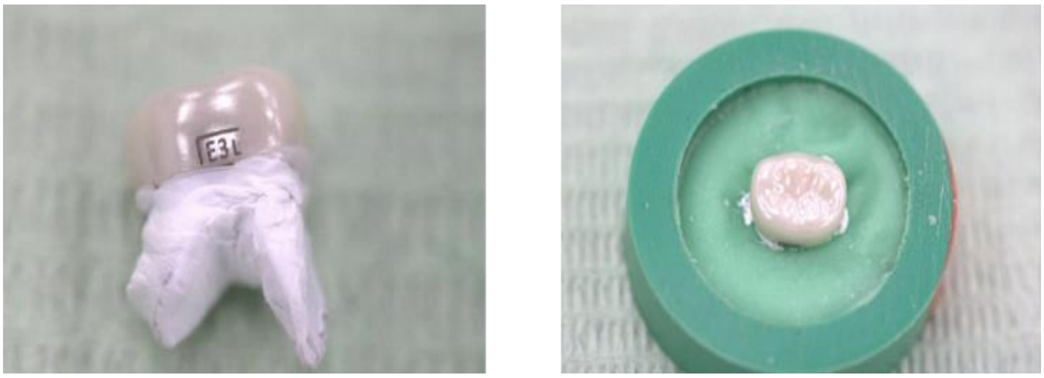

Fig 12: Preparation of specimen from group A for fracture resistance test, a) Teflon tape wrapped around the root, b) Tooth mounting in self-cure acrylic resin.

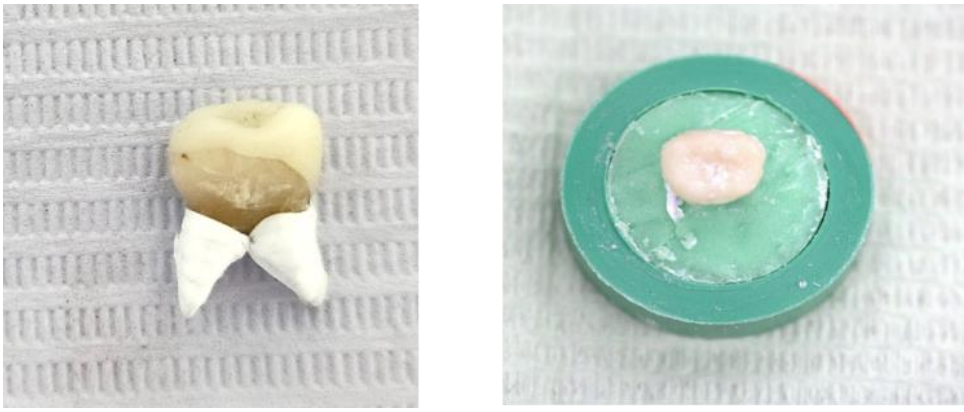

Fig 13: Preparation of specimen from group B for fracture resistance test, a) Teflon tape wrapped around the root, b) Tooth mounting in self-cure acrylic resin.

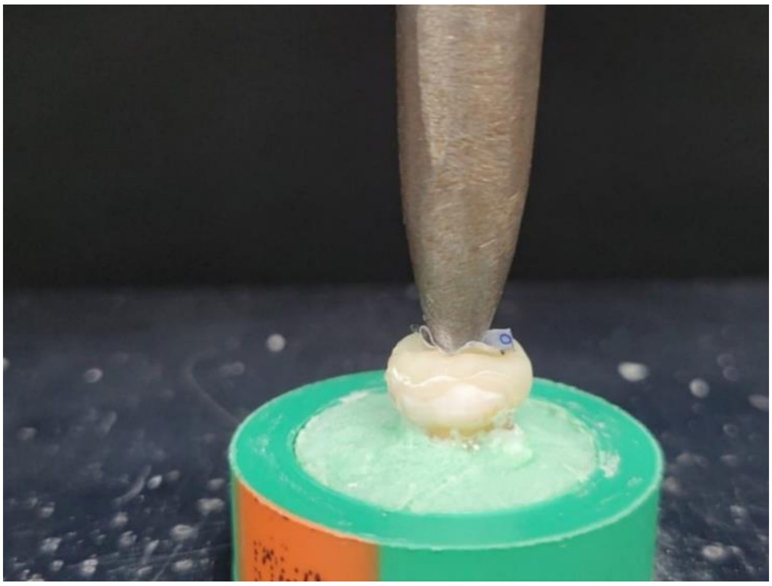

Fig 14: Axial loading of Endocrown specimen.

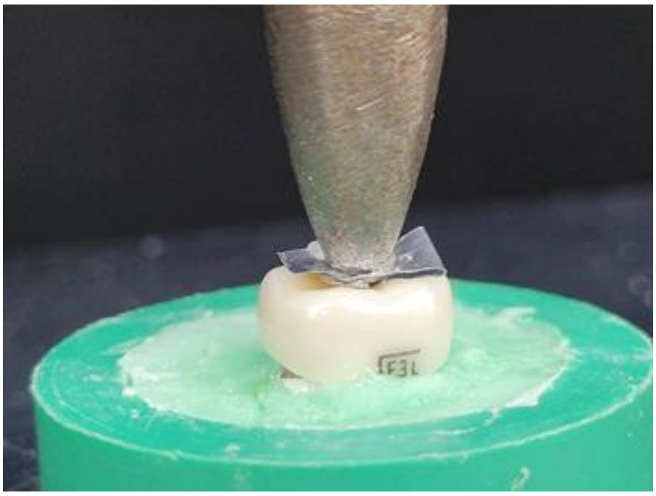

Fig. 15:Axial loading of zirconia crown specimen

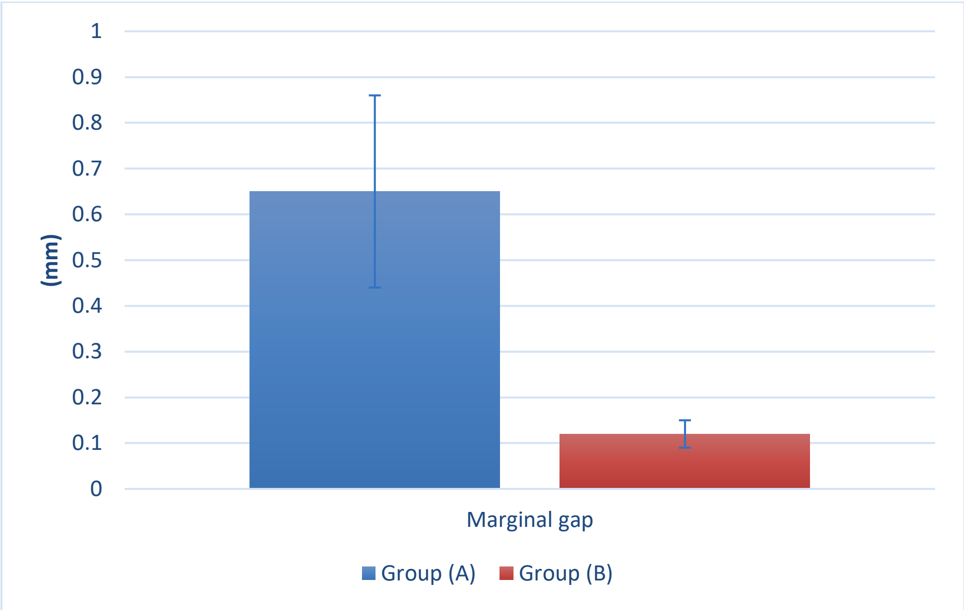

Fig 16: Stacked bar chart showing mean and standard deviation values for marginal gap values (mm)

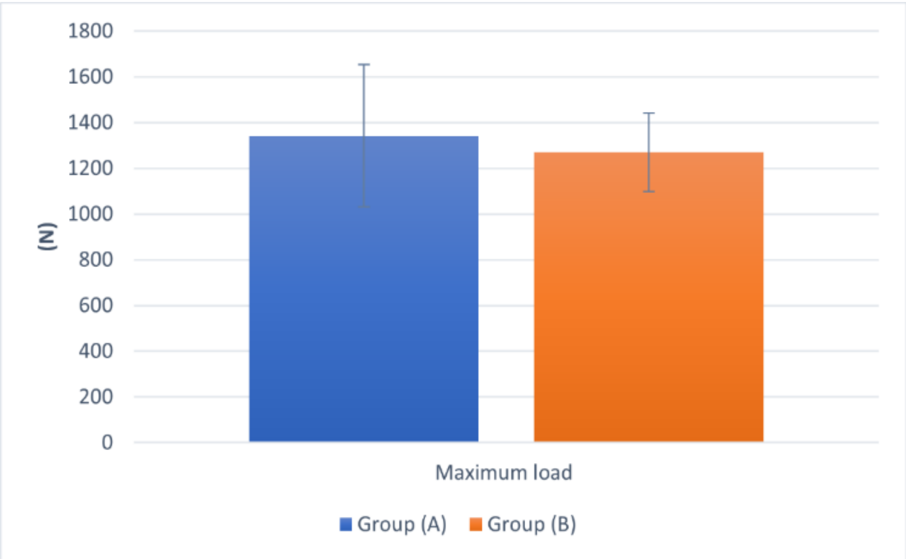

Fig 17: Stacked bar chart showing mean and standard deviation values for maximum load values (N)

The authors in the previous study sectioned the crowns in a buccolingual direction, and a stereomicroscope was used to measure the marginal and internal gap of the tested crowns. The limitation of using such a technique is that it gives a two-dimensional (2D) view for measuring the thickness of the gap in a single section and does not examine 3D adaptation, unlike our study where the specimens were examined from all aspects without sectioning. In 2022, a systematic review[24] evaluated the marginal fit and internal adaptation of provisional crowns and fixed dental prostheses (FDPs) fabricated using 3D-printing resins and compared them with those fabricated by CAD/CAM milling and conventional resins. The researchers concluded that provisional crowns and FDPs fabricated from 3D-printing resins had a superior marginal fit and internal adaptation when compared to CAD/CAM-milled and conventional provisional resins. In CAD/CAM milling, the manufacturing process is affected by the size of the milling bur and its range of cutting movement, whereas, in 3D-printing, there is an incremental layering process, which reproduces details accurately and compensates for polymerization shrinkage. It should be noted that the milling technique cannot precisely refine the rugged surfaces and sharp edges due to the limitations in size, angles, and movements of the cutting instrument[25]. Although the previously mentioned systematic review[24]did not involve any studies on ECs, it would be expected that 3D printing would enhance the marginal fit of endocrowns. However, Further investigations are needed to further confirm this.

5. Conclusions

Within the limitations of the current study, it can be concluded that:

1. A statistically significant difference in the marginal gap values was found between zirconia crowns and endocrowns groups with zirconia crowns having significantly higher values than endocrowns.
2. No significant difference was found between zirconia crown and endocrown groups regarding fracture resistance.

Acknowledgements

The authors wish to express their gratitude to ***Dr. Ahmad El-Shennawy*** who performed the 3D-printing of the endocrowns and ***Dr.Bassam Aboulnoor*** who conducted the statistical analysis of the study results. The authors do not have any financial interest in the companies whose materials are included in this article.

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