ORIGINAL RESEARCH

Comparative Analysis of Marginal Fit and Fracture Resistance in CAD-CAM Lithium Disilicate and Pre-processed Composite Endocrowns: An *In Vitro* Study

Manorama Vijay Singh[1], Hasan Sarfaraz[2], Stephan Lampl[3], Deepak Mehta[4], Deepa Gurunathan[5]

Received on: 02 September 2024; *Accepted on*: 30 October 2024; *Published on*: 26 November 2024

Abstract

Aim and background: This study aimed to determine the optimal finish line and material criteria for optimal marginal fit and fracture resistance in endocrowns. The impact of two preparation designs on endocrowns made from computer-aided design and computer-aided manufacturing (CAD-CAM) lithium disilicate and pre-processed CAD/CAM composite was compared.

Materials and methods: In a randomized 3-arm trial involving 42 mandibular molars, two marginal configurations (with and without chamfer finish lines) were evaluated for each material group. Marginal fit was assessed pre- and post-cementation using scanning electron microscope, and fracture resistance was tested with a universal testing machine. Student *t*-test was used to compare within group differences and ANOVA with Tukey test was used to compare intergroup differences. The significance level was set at 0.05.

Results: Edelweiss CAD/CAM blocks demonstrated the least marginal gap pre- and post-cementation, and superior fracture resistance compared to lithium disilicate and HIPC composite resin. Finish lines significantly affected marginal adaptation in all groups. Fracture resistance differences between designs within the same group were not statistically significant.

Conclusion: The CAD/CAM composite proved effective for endocrown restorations, with finish lines impacting marginal adaptation but not fracture resistance. Edelweiss CAD/CAM blocks showed superior performance in both aspects, suggesting their suitability for such restorations.

Clinical significance: The study highlights the clinical significance of using Edelweiss CAD/CAM blocks for endocrown restorations, demonstrating superior marginal fit and fracture resistance. Clinicians can enhance restoration longevity by selecting appropriate materials and preparation designs, particularly the use of finish lines, to optimize marginal adaptation without compromising fracture resistance.

Keywords: Endocrown materials, Fracture strength, Marginal adaptation, Preparation design.

The Journal of Contemporary Dental Practice (2024): 10.5005/jp-journals-10024-3749

Introduction

The traditional requirement for a post, core, and crown has diminished significantly with the advancements in adhesive systems.[1] In this context, endocrowns have emerged as a minimally invasive alternative to conventional methods, particularly in posterior teeth.[2] This approach offers several advantages, including the preservation of tooth structure, reduced preparation time, enhanced esthetics, shorter chair time, and improved stress distribution.[2,3] These benefits have contributed to the growing popularity and widespread application of endocrowns in restorative dentistry. Esthetic appeal, resistance to fracture, and marginal adaptation are key determinants of the effectiveness of dental restorations. Among these, marginal adaptation stands out as a critical element for the success of any restoration, as inadequate marginal adaptation heightens the risk of microleakage, plaque accumulation, secondary caries, periodontal disease, and compromised esthetics.[4]

Several studies have explored the impact of different preparation designs on conventional crowns and note that an escalation in the marginal gap may diminish the fracture strength of ceramics.[5] This phenomenon also poses risks such as cement dissolution, heightening the potential for secondary caries, and contributing to issues like microleakage and periodontal disease.[5,6] Gavelis et al. in their study note that butt joint finish margins could establish a more effective escape pathway for the luting agent, facilitating improved crown seating. Available data indicates that the acceptable range for vertical marginal gaps typically falls

[1]Department of Prosthodontics, Yenepoya Dental College, Yenepoya Deemed to be University, Deralakatte, Mangaluru, Karnataka, India

[2]Department of Oral Implantology, Yenepoya Dental College, Yenepoya Deemed to be University, Deralakatte, Mangaluru, Karnataka, India

[3,5]Department of Pediatric Dentistry, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

[4]Department of Operative Dentistry, Tohoku University Graduate School of Dentistry, Tohoku University, Sendai, Japan; Department of Cariology, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

Corresponding Author: Deepa Gurunathan, Department of Pediatric Dentistry, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India, Phone: +91 9994619386, e-mail: deepag@saveetha.com

How to cite this article: Singh MV, Sarfaraz H, Lampl S, *et al*. Comparative Analysis of Marginal Fit and Fracture Resistance in CAD-CAM Lithium Disilicate and Pre-processed Composite Endocrowns: An *In Vitro* Study. J Contemp Dent Pract 2024;25(8):732–739.

Source of support: Nil

Conflict of interest: Dr Deepak Mehta is associated as the Editorial Board member of this journal and this manuscript was subjected to this journal's standard review procedures, with this peer review handled independently of this editorial board member and his research group.

between 10 and 160 μm.[6] Two commonly used material classes in the manufacturing of computer-aided design and computer-aided manufacturing (CAD/CAM) restorations include glass-ceramics/ceramics and composite resins.[7] Although glass-ceramics generally exhibit superior mechanical and aesthetic characteristics, resin-composite materials offer notable advantages in terms of machinability and intraoral reparability.[7] In contemporary metal-free dentistry, lithium disilicate has emerged as the preferred restorative material due to its high flexural strength, relatively elevated fracture toughness, optimal light optical properties, and the ability to achieve a monoblock effect, along with increased adhesion values.[4] However, the absence of the monoblock effect can lead to debonding, and potential fracture of these restorations. Since their introduction in 2000, pre-processed composite resin blocks have undergone significant advancements and have been recommended for indirect posterior restorations.[7] The CAD/CAM composite blocks have exhibited promising results as a material of choice for fabricating endocrowns as their physical properties closely resemble those of dentin, ensuring superior stress distribution.[8] Recent advancements have introduced high-performance composite resin materials tailored for CAD/CAM applications. Given the limited research on CAD/CAM composite blocks, there is a need to assess the properties of this material. On the backdrop of this evidential premise, the *in vitro* study presented herein evaluates the effect of preparation design on the marginal fit and the fracture resistance of endocrowns fabricated using lithium disilicate and pre-processed CAD/CAM composites.

Materials and Methods

Study Design

This randomized, 3-arm study in 42 intact or mildly carious mandibular molars compared the marginal fit and fracture resistance of two marginal configurations (designs 1 and 2) of endocrowns fabricated using lithium disilicate (Group A (LD); $n = 14$), HIPC composite resin (Group B (CB); $n = 14$) and edelweiss CAD/CAM blocks (Group C (CE); $n = 14$). Furthermore, each group was stratified based on the marginal configurations (design 1 and 2). Thus, each group consisted of 2 equal subgroups (Groups A1 ($n = 7$) and A2 ($n = 7$); Groups B1 ($n = 7$) and B2 ($n = 7$); Groups C1 ($n = 7$) and C2 ($n = 7$)). Only mandibular molars without significant loss of tooth structure were included in the study and those with signs of fracture, crack lines and decay were excluded. All the procedures of this study were done by the same operator using the same sequence as described below (Table 1).

Table 1: Description of materials used in the study

Material	*Description*	*Manufacturer*
Lithium disilicate	IPS e.max® CAD Lithium disilicate glass-ceramic (LS2) | Lithium-Disilikat Glaskeramik (LS2)-LT, C 14-A2 shade.	Ivoclar, Germany
High impact polymer composite	BreCAM. HIPC Milling blank, 98,5 mm with 10mm fold 20mm AG–A2 shade	Bredent, UK
Edelweiss CAD/CAM block	Edelweiss CAD/CAM A2-14 mm Block	Edelweiss, Austria

Endodontic Treatment

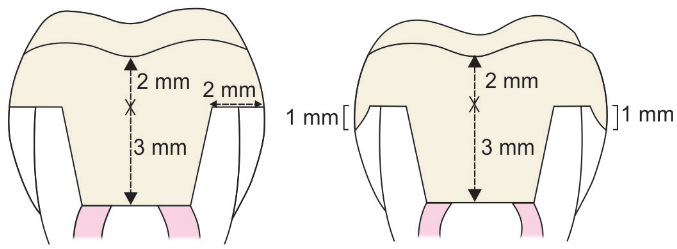
The root canal treatment was performed using the rotary file system. Following assessments of pulp chamber morphology, the axis opening of each tooth was done using a round carbide high-speed bur (Mani Endo Access Diamond Burs). For standardization of root canal treatment, F1 (Dia-ProT Gutta percha) and F2 (Dia-ProT Gutta percha) were used as master files for mesial and distal canals, respectively. During preparation, the mesial and distal canals were irrigated with 3% NaOCL (iSod-H, I-MED Industries) after use of each file. After the adequate cleaning, shaping and irrigation of the canals, the root canals were dried with absorbent paper points, and mesial canals were obturate with size F1(Dia-ProT Gutta percha) gutta-percha and distal canals were obturate with size F2 (Dia-ProT Gutta percha) gutta-percha. The orifice was sealed using resin-based root canal sealants (Meta Adseal, Resin-Based Sealer). The pulp chamber was restored using a flowable and restorative composite resin (Tetric N-Flow Ivoclar vivadent).

Tooth Preparation

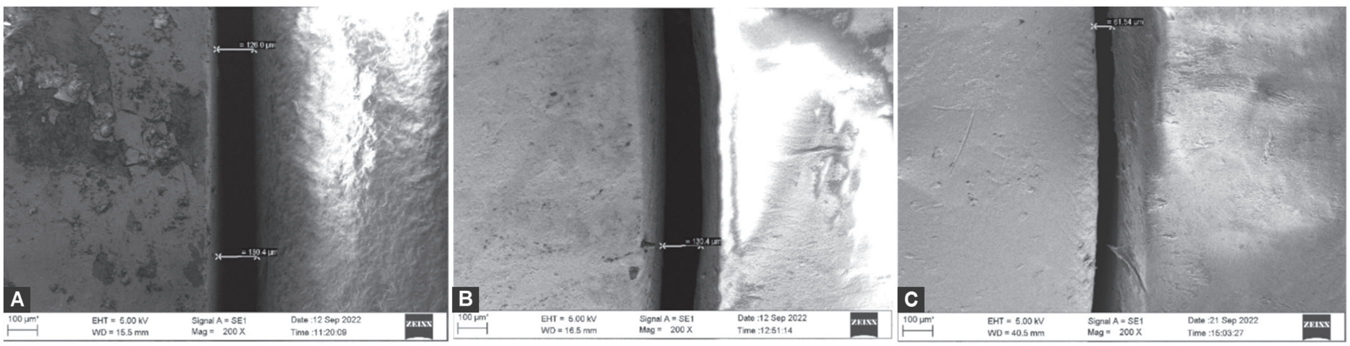
All the selected teeth ($n = 42$) were extracted, and cleaned with distilled water, and stored in saline. Within 90 days of extraction, teeth were randomly assigned to the experimental groups and their respective design strata. Subsequently, the teeth from each group were vertically mounted in autopolymerizing acrylic resin, with the roots embedded in resin up to 2 mm below the cementoenamel junction (CEJ). For the purposes of standardization, tooth preparation of each sample was performed with a new round end taper bur (Dental Mani Diamond Burs TF-21EF). Occlusal reduction of 2 mm of the included molars was achieved by placing the depth orientation grooves on the remaining occlusal surface. The internal axial walls of the access cavity of the included tooth were prepared to a depth of 3 mm using a flat-end taper (Dental Mani Diamond Burs TF-13) with a divergent taper of 6–8 degrees. Samples included in design 1 ($n = 21$), did not undergo any preparation of the external axial walls of the tooth, and the external axial wall samples in design 2 ($n = 21$) were prepared to a depth of 1 mm with a 45 degree chamfer finish line (Fig. 1).

Fabrication of Endocrowns

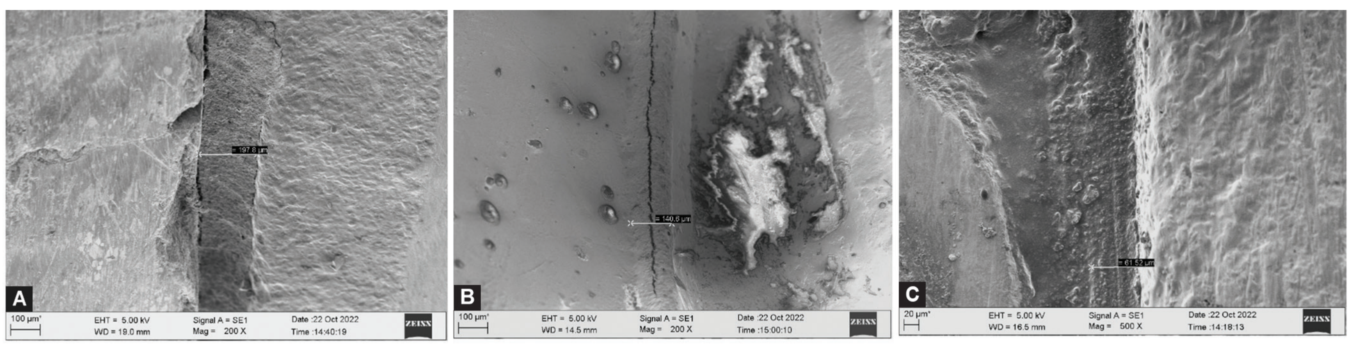
Polyvinyl siloxane impression material was used to obtain the impression of each tooth sample ($n = 42$). For CAD/CAM fabrication of the endocrowns, equal amount of base and catalyst (Dentsply Aquasil Soft Putty Regular Set) were hand manipulated and loaded into the custom tray. Light body elastomeric impression material (3M™ Express™ VPS impression material light body regular set refill) was flown on to the prepared tooth. The loaded tray was seated firmly and allowed to be set for 5 minutes as per the manufacturer's recommendation. The impression was then poured with type IV (Dental Die Stone by ASIAN CHEMICALS Pearlstone) dental stone. The stone was mixed according to the manufacturer's specifications (water/powder ratio of 0.20 mL/gm, 60 seconds manual manipulation followed by mechanical manipulation under vacuum for 30 seconds). The stone was poured into the impression by placing the impression on a vibrator. The stone was left to settle for 45 minutes–1 hour, according to the manufacturer's recommendations. Subsequently, all the 42 stone dies were scanned using a lab scanner (Ceramill® map 400 Amann Girrbach). Scanned data were converted into CAD data, and endocrowns were designed with identical dimensions (2 mm of occlusal thickness and 3 mm of interradicular extension). A uniform cement space of 125 μm



Figs 1A and B: Line diagram representing preparation designs: (A) Butt joint; (B) Chamfer finish line



Figs 2A to C: SEM images of marginal gap evaluation pre-cementation for butt joint finish line. (A) Group A; (B) Group B; (C) Group C



Figs 3A to C: SEM images of marginal gap evaluation post-cementation for butt joint finish line. (A) Group A; (B) Group B; (C) Group C

was given for all 42 samples using the computer-aided designing software (Ceramill® mind Amann Girbach) and these were milled in lithium disilicate and composite resin blank using a milling machine (Ceramill® motion2, Amann Girbach). Endocrowns milled with lithium disilicate were kept for crystallization firing, followed by glaze firing. And endocrowns milled with HIPC composite resin and edelweiss composite were polished using a composite polishing brush and buff.

Marginal Gap Testing

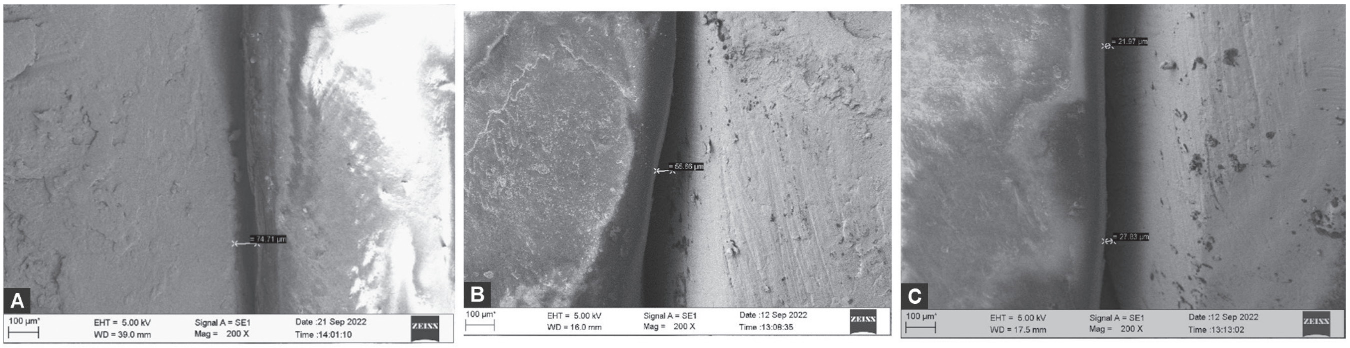
In this study, marginal gap was examined using a scanning electron microscope (EVO MA18 with Oxford EDS(X-act) under X200 magnification after gold sputtering. The marginal gap was measured at mid-buccal, mesiobuccal, distobuccal and mid-lingual regions along with mesiolingual, distolingual, mid-distal, and mid-mesial regions. Endocrown restoration was stabilized to the prepared tooth using aluminum tape (EM-Tec single-sided conductive aluminum SEM tapes). Measurements were recorded precementation and postcementation (Figs 2 to 5).

Mechanical Loading

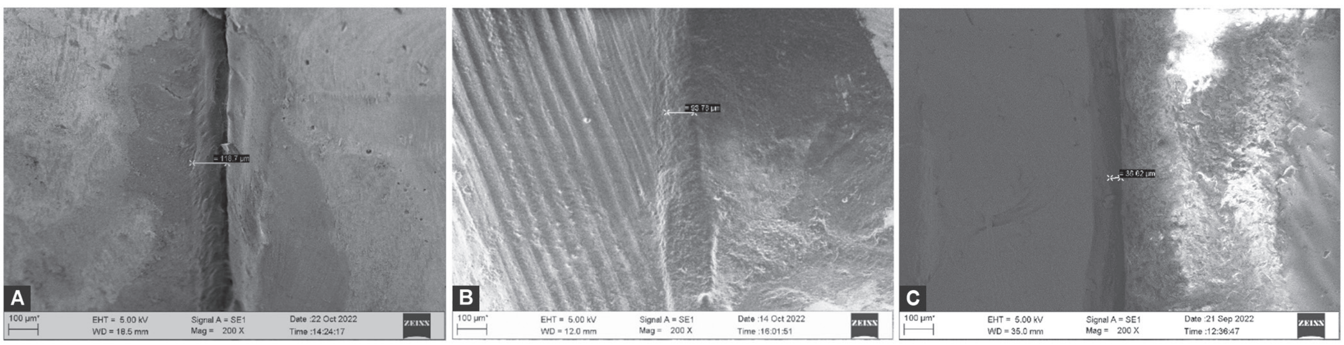
All 42 samples were bonded using a bonding protocol specific to the material used for fabricating endocrowns. Samples were mounted in acrylic resin (DPI R.R Cold Cure) and loaded vertically in the center of occlusal surface in a universal testing machine until fracture occurred. The loading piston was placed in center along the long axis of the mounted tooth with a 9 mm diameter steel ball and the crosshead speed of the machine was 0.5 mm/min. The fracture resistance was recorded in Mega-Pascals (MPa). Furthermore, the fractured samples were visually inspected for mode of fracture.

Statistical Analysis

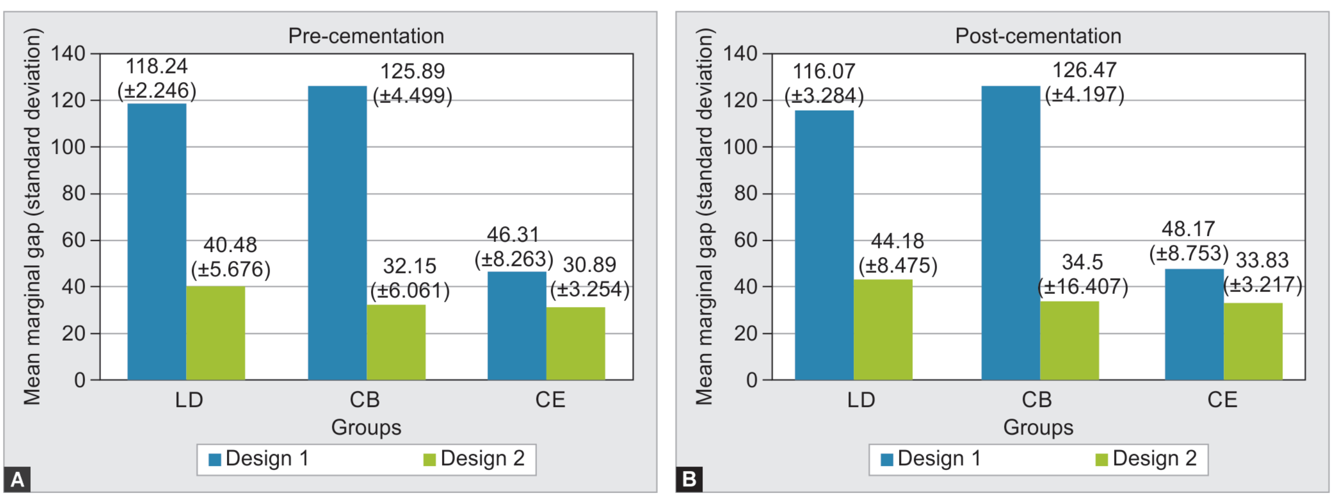
Data were collected and tabulated to arrive at descriptive statistics. Continuous data were expressed as mean ± standard deviation. The Student t-test was used to compare differences in marginal fit and fracture resistance between designs 1 and 2 for each of the three materials evaluated in the study. Analysis of variance technique (ANOVA) was used to compare differences in marginal fit and



Figs 4A to C: SEM images of marginal gap evaluation pre-cementation for chamfer finish line. (A) Group A; (B) Group B; (C) Group C



Figs 5A to C: SEM images of marginal gap evaluation post-cementation for chamfer finish line. (A) Group A; (B) Group B; (C) Group C



Figs 6A and B: Comparison of marginal gaps between groups and within groups in: (A) Pre-cementation; (B) Post-cementation phases

*Design 1 vs design 2: $p < 0.05$ in all the groups; **Group C vs group A ($p < 0.05$); †Group C vs group B ($p < 0.05$)

fracture resistance between the six groups. The Tukey HSD test was used for multiple comparisons. The level of significance was set at 0.05. All statistical tests were performed using (version 22; IBM).

Results

Overall, 42 mandibular molars randomly allocated to three groups stratified by marginal design configuration were evaluated in the study. Figure 6 presents the differences between groups in marginal gap values at pre-cementation (Fig. 6A) and post-cementation stages (Fig. 6B). In each of the groups, the marginal gap was significantly higher for design 1 as compared to design 2 ($p < 0.05$) in both pre- and post-cementation stages. Furthermore, the results of the ANOVA indicated that the marginal gap differed between groups ($p < 0.05$). Furthermore, *post-hoc* comparisons using the Tukey HSD test indicated that the marginal gap was lowest with edelweiss CAD/CAM block as compared to lithium disilicate (Group A; $p < 0.05$) and HIPC composite resin (Group B; $p < 0.05$) in both pre- and post-cementation stages.

With respect to assessments of fracture strength, results of the current study indicated that there were no statistically significant differences between design 1 and design 2 in groups A, B and

C. However, statistically significant differences were noted for the mean fracture resistance between groups (Fig. 7; $p < 0.05$). *Post-hoc* comparisons using the Tukey HSD test indicated that fracture resistance was better with edelweiss CAD/CAM block (group C) as compared to lithium disilicate (group A; $p < 0.05$) and HIPC composite resin (group B; $p < 0.05$). Furthermore, fracture characterizations using Burke classification indicated that the most commonly occurring fractures in lithium disilicate (group A), HIPC composite resin (group B) and edelweiss CAD/CAM block (group C) belonged to class V (severe fracture of crown and/or tooth), class III (half of crown displaced or lost) and class II (less than half of crown lost), respectively (Fig. 8).

Discussion

Advancements in adhesive dentistry have largely obviated the need for macroretentive designs as a prerequisite for successful restorations.[1] Currently, endocrown restorations have emerged as recommended choices, especially in posterior areas and molars with thin roots, calcified root canals, or short clinical crown height.[1–3] Nevertheless, along with margin design, several material-related factors, including thickness, elastic moduli, bond strength and ability to withstand occlusal load, are known to influence the

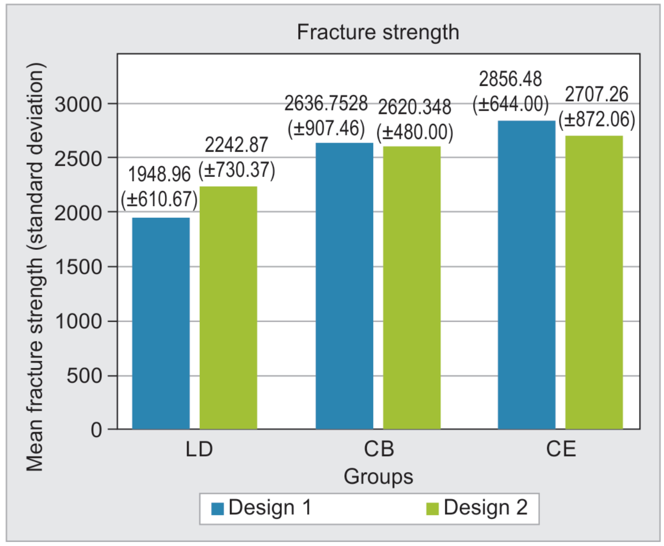


Fig. 7: Comparison of fracture resistance between groups and within groups

*Design 1 vs Design 2: (insert *p*-value) in all the groups; **Group C vs Group A ($p < 0.05$); †Group C vs Group B ($p < 0.05$)

Figs 8A to C: Example of fractured specimens. (A) Class V fracture (common in lithium disilicate group); (B) Class III fracture (common in HIPC composite resin group); (C) Class I (common in edelweiss CAD/CAM block) success of endocrown restorations.[4–8] Furthermore, fractures arising as a result of stress due to functional forces are a common complication of endodontically treated teeth. In these contexts, bonded restorations are known to provide a monoblock effect, which, along with supporting a full coverage restoration, also improves the strength of the endodontically treated teeth.[9]

Lithium di silicate, feldspathic ceramics or monolithic zirconia are common material choices for fabricating endocrowns.[10,11] Otto et al. note that the high elastic modulus of materials such as ceramic may transmit stress at the tooth-to-material bonded interface.[12] This could potentially lead to a non-repairable fracture of the clinical crown extending up to the roots and compromise the longevity of endocrowns.[13] Furthermore, low residual height (< 2 mm) of the crown axial wall can have a negative impact on the longevity of endocrowns. In these contexts, newer CAD/CAM composites with an elastic modulus close to dentine may decrease the stress transmitted to the tooth or the cement layer by concentrating the stress of the material itself, with resultant reductions in endocrown failures. On the premise of these considerations, the *in-vitro* study presented herein compared lithium disilicate and two different pre-processed CAD/CAM composite for their strength to withstand the occlusal load.

Although, the recommended classical finish line for endocrowns is a 90-degree butt joint, which would provide for a flat surface and increases strength against compressive forces.[14] Several studies indicate that adding a ferrule may offer greater fracture resistance to endocrown-restored teeth by increasing their surface area for bonding by approximately 47% and providing for better marginal adaptation of endocrown restorations.[15,16] Thus, the present study compared a conventional design without any finish margin with a design that included a chamfer finish line on the external axial wall. Results of the current study indicate that these two design configurations and the materials used to fabricate them do not influence the fracture resistance of endocrowns. This observation is in line with the findings of another study by Haralur et al., which demonstrated no significant effect of finish line design (shoulder or deep chamfer) on fracture resistance of endocrowns fabricated using lithium disilicate.[17] Another study by Zheng et al. noted a more favorable outcome for endocrown restorations with 20 degrees of margin bevel and Taha et al. in their study reported higher fracture resistance for shoulder finish line in comparison to butt joint, despite the similarity of mode of failure in both finish lines.[16,18] These evidence along with results of the current study seem to indicate that a chamfer finish line would provide sufficient strength along with better marginal adaptation to endocrown restorations. Furthermore, a systematic review by Mostafavi et al. indicates that fracture resistance of standard and modified endocrowns in terms of margin design is beyond the normal masticatory force range.[19] Thus, excessive preparation to increase fracture resistance may not be necessary.

The study reported herein is an addition to the relatively scanty literature comparing CAD/CAM composites with lithium disilicate for fabricating endocrowns. In the present study, two CAD/CAM composite groups that were evaluated included high impact polymer composite (HIPC) which is an amorphous cross-linking composite material, and edelweiss CAD/CAM composite which is uniquely manufactured by vitrification and layer sintering process. These manufacturing processes could enhance flexibility and offer high strength to the edelweiss CAD/CAM composite. Results of the current study indicate that the fracture resistance of the CAD/CAM composite was significantly higher than that of the lithium disilicate endocrowns ($p < 0.05$). These results are in agreement with the findings of other studies by Sedrez-Porto et al. and Damanhoury et al., which indicated less aggressive fractures and high fracture resistance of direct composite endocrowns in comparison to ceramic endocrowns.[20,21] However, another study by Altier et al. noted a higher fracture resistance with lithium disilicate ceramic endocrowns as compared to indirect composite materials.[22] Overall, it appears that the heterogeneity with respect to choice of composites may contribute to these opposing observations reported in current literature and merits a clarification of these considerations in future studies. Nevertheless, in the current study, the elastic modulus of composite resin may have influenced the modulus development within the restoration leading to a more compatible biomechanical behavior than lithium disilicate which is brittle and transfers more stress to the pulp chamber and axial walls of the tooth.[18]

In this study, the marginal fit of endocrowns was evaluated both before and after cementation. Consistent with previous research, a significant increase in the marginal gap was observed following cementation.[23] Results of the present study show that in the pre-cementation and postcementation evaluations, endocrowns fabricated using the HIPC composite showed the highest mean marginal gap of 125.89 ± 4.499 μm and 126.47 ± 4.197 μm respectively, whereas endocrowns fabricated using the edelweiss CAD/CAM composite showed the least mean marginal gap of 30.89 ± 3.524 μm and 33.83 ± 3.217 μm, respectively. These findings are in line with another study by Al-Akhali et al., which noted mean marginal gap values of 56.6 ± 6.1 μm for lithium disilicate and 81.3 ± 10.1 μm for PEEK endocrowns.[24] Furthermore, another study by Ewadh et al. demonstrated that resin-nano ceramic endocrowns exhibit superior marginal fit compared to glass ceramic endocrowns.[25]

Results of the current study indicate that the designs with a chamfer finish line preparation resulted in significantly less marginal gap compared to the butt joint design across all materials evaluated. In contrast to these findings, a study by AL-Zomur et al. in 2021 reported that the butt joint design yielded better marginal integrity compared to the shoulder finish line design.[26] These discrepancies may be attributable to variations in the restoration material (IPS e.max press vs IPS e.max CAD or hybrid composites) and the type of teeth evaluated (mandibular premolars vs mandibular molars). Additionally, as CAD/CAM composites are relatively softer materials, they can be more easily machined compared to brittle glass ceramics. However, no previous studies have compared the chamfer finish line to the conventional butt joint margin for endocrowns. This study sought to investigate these finish line designs, as the chamfer finish line could potentially help preserve more tooth structure while providing superior marginal integrity compared to shoulder or butt joint finish lines.

Furthermore, in this study, the fractured specimens and fragments were collected, and the mode of fracture was examined visually. In agreement with the findings of Altier et al.,[22] which noted that failure modes were favorable for composite groups, results of the current study indicate that lithium disilicate fractured along with the tooth and edelweiss CAD/CAM composite had line repairable fracture at the same load (Fig. 8). The CAD/CAM composite material has a combination of high flexural strength and resilience due to its cross-linked polymer structure, which prevents crack propagation. On the other hand, lithium disilicate is composed of glass and hence is a brittle material. These material properties may explain the type of fractures observed in the present study.

Chewing simulations to account for aging processes were not performed in this study. However, it is pertinent to note that data from Sieper et al. and Al-Akhali et al. present contradictory results on the influence of aging with thermocycling on the fracture resistance of materials.[24,27] Additionally, bond strength and the effect of the intra-coronal extension dimension on fracture resistance were not evaluated in these studies.[27,28] In this study, extracted mandibular molars were used after obturating the root canals with endodontic obturating material to simulate the clinical scenario. Nevertheless, a key limitation of this study is that it did not simulate an intraoral environment. Despite these limitations, the current study indicates a statistically significant difference in the fracture resistance, of the materials evaluated. However, there was no significant influence of margin design on fracture resistance. Milled edelweiss CAD/CAM composite showed the highest fracture resistance which can be attributed to the inherent properties of the material as well as the unique manufacturing process. The mode of fracture observed in the composite group was also favorable.

Conclusion

In conclusion, the mean marginal gap values and fracture resistance (well exceeding the masticatory forces) of all tested materials and preparation designs were within the clinically acceptable range. Furthermore, designs with chamfer finish lines resulted in lower gaps compared to butt joint finish lines across materials. The pre-processed CAD/CAM composite group exhibited the most favorable marginal gap and better fracture strength as compared to lithium disilicate.

Clinical Significance

This study underscores the clinical importance of selecting optimal materials and preparation designs for endocrowns. Edelweiss CAD/CAM blocks exhibited superior marginal fit and fracture resistance, suggesting their suitability for durable restorations. The findings guide clinicians in improving restoration outcomes by emphasizing the role of material choice and finish line design.

References

1. Sevimli G, Cengiz S, Oruc MS. Endocrowns: review. J Istanb Univ Fac Dent 2015;49(2):57–63. DOI: 10.17096/jiufd.71363.
2. Ansari SH, Alfaqeeh AA, Buryk AA, et al. Indications and success rate of endo crowns--A systematic review. J Evolution Med Dent Sci 2020;9(43):3247–3252. DOI: 10.14260/jemds/2020/712.
3. Bao XD. [Advantages and disadvantages of endocrown restorations of endodontically treated teeth with large coronal destruction]. Zhonghua Kou Qiang Yi Xue Za Zhi 2018;53(4):221–225. DOI: 10.3760/cma.j.issn.1002-0098.2018.04.002.
4. Contrepois M, Soenen A, Bartala M, et al. Marginal adaptation of ceramic crowns: A systematic review. J Prosthet Dent 2013;110(6):447–454.e10. DOI: 10.1016/j.prosdent.2013.08.003.
5. Sirous S, Navadeh A, Ebrahimgol S, et al. Effect of preparation design on marginal adaptation and fracture strength of ceramic occlusal veneers: A systematic review. Clin Exp Dent Res 2022;8(6):1391–1403. DOI: 10.1002/cre2.653.
6. Gavelis JR, Morency JD, Riley ED, et al. The effect of various finish line preparations on the marginal seal and occlusal seat of full crown preparations. J Prosthet Dent 1981;45(2):138–145. DOI: 10.1016/0022-3913(81)90330-9.
7. Ruse ND, Sadoun MJ. Resin-composite blocks for dental CAD/CAM applications. J Dent Res 2014;93(12):1232–1234. DOI: 10.1177/0022034514553976.
8. Magne P, Schlichting LH, Maia HP, et al. In vitro fatigue resistance of CAD/CAM composite resin and ceramic posterior occlusal veneers. J Prosthet Dent 2010;104(3):149–157. DOI: 10.1016/S0022-3913(10)60111-4.
9. Bitter K, Kielbassa AM. Post-endodontic restorations with adhesively luted fiber-reinforced composite post systems: A review. Am J Dent 2007;20(6):353–360. PMID: 18269124.
10. Kanat-Ertürk B, Saridağ S, Köseler E, et al. Fracture strengths of endocrown restorations fabricated with different preparation depths and CAD/CAM materials. Dent Mater J 2018;37(2):256–265. DOI: 10.4012/dmj.2017-035.
11. Zou Y, Bai J, Xiang J. Clinical performance of CAD/CAM-fabricated monolithic zirconia endocrowns on molars with extensive coronal loss of substance. Int J Comput Dent 2018;21(3):225–232. PMID: 30264051.
12. Otto T, Mörmann WH. Clinical performance of chairside CAD/CAM feldspathic ceramic posterior shoulder crowns and endocrowns up to 12 years. Int J Comput Dent 2015;18(2):147–161. PMID: 26110927.
13. Bajraktarova-Valjakova E, Korunoska-Stevkovska V, Kapusevska B, et al. Contemporary dental ceramic materials, a review: Chemical composition, physical and mechanical properties, indications for use. Open Access Maced J Med Sci 2018;6(9):1742–1755. DOI: 10.3889/oamjms.2018.378.
14. Pissis P. Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Pract Periodontics Aesthet Dent 1995;7(5):83–94. PMID: 7548896.
15. Einhorn M, DuVall N, Wajdowicz M, et al. Preparation ferrule design effect on endocrown failure resistance. J Prosthodont 2019;28(1):e237–e242. DOI: 10.1111/jopr.12671.
16. Taha D, Spintzyk S, Schille C, et al. Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. J Prosthodont Res 2018;62(3):293–297. DOI: 10.1016/j.jpor.2017.11.003.
17. Haralur SB, Alamrey AA, Alshehri SA, et al. Effect of different preparation designs and all ceramic materials on fracture strength of molar endocrowns. J Appl Biomater Funct Mater 2020;18:2280800020947329. DOI: 10.1177/2280800020947329.
18. Zheng Z, Sun J, Jiang L, et al. Influence of margin design and restorative material on the stress distribution of endocrowns: A 3D finite element analysis. BMC Oral Health 2022;22(1):30. DOI: 10.1186/s12903-022-02063-y.
19. Mostafavi AS, Allahyari S, Niakan S, et al. Effect of preparation design on marginal integrity and fracture resistance of endocrowns: A systematic review. Front Dent 2022;19:37. DOI: 10.18502/fid.v19i37.11250.
20. Sedrez-Porto JA, Rosa WL de O da, da Silva AF, et al. Endocrown restorations: A systematic review and meta-analysis. J Dent 2016;52:8–14. DOI: 10.1016/j.jdent.2016.07.005.
21. El-Damanhoury HM, Haj-Ali RN, Platt JA. Fracture resistance and micro leakage of endocrowns utilizing three CAD-CAM blocks. Oper Dent 2015;40(2):201–210. DOI: 10.2341/13-143-L.
22. Altier M, Erol F, Yildirim G, et al. Fracture resistance and failure modes of lithium disilicate or composite endocrowns. Niger J Clin Pract 2018;21(7):821–826. DOI: 10.4103/njcp.njcp_175_17.
23. Halıcı SE, Hekimoğlu C, Ersoy O. Marginal fit of all-ceramic crowns before and after cementation: An in vitro study. Int J Periodontics Restorative Dent 2018;38(3):e41–e48. DOI: 10.11607/prd.3169.
24. Al-Akhali M, Chaar MS, Elsayed A, et al. Fracture resistance of ceramic and polymer-based occlusal veneer restorations. J Mech Behav Biomed Mater 2017;74:245–250. DOI: 10.1016/j.jmbbm.2017.06.013.
25. Ewadh AM, Jasim HH. The influence of different CAD/CAM materials on the marginal fit of endocrown with different cavity depths

(A comparative in-vitro study). Materials Today Proceedings 2022;61(5):695–699. DOI: 10.1016/j.matpr.2021.08.261.
26. AL-Zomur S, Abo-Madina M, Hassouna M. Influence of different marginal preparation designs and materials on the marginal integrity and internal adaptation of endocrown restorations. Egyptian Dental Journal 2021;67(4):3491–3500. DOI: 10.21608/edj.2021.85048.1710.
27. Sieper K, Wille S, Kern M. Fracture strength of lithium disilicate crowns compared to polymer-infiltrated ceramic-network and zirconia reinforced lithium silicate crowns. J Mech Behav Biomed Mater 2017;74:342–348. DOI: 10.1016/j.jmbbm.2017.06.025.
28. Godil AZ, Kazi AI, Wadwan SA, et al. Comparative evaluation of marginal and internal fit of endocrowns using lithium disilicate and polyetheretherketone computer-aided design – computer-aided manufacturing (CAD-CAM) materials: An in vitro study. J Conserv Dent 2021;24(2):190–194. DOI: 10.4103/JCD.JCD_547_20.