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Original Article

Comparative analysis of endocrown fracture resistance and marginal adaptation: CAD/CAM technology using lithium disilicate vs. zirconia-reinforced lithium silicate ceramics

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ABSTRACT

Aims: The present study aimed to compare the fracture resistance and marginal adaptation of endocrowns fabricated using lithium disilicate (LDS) and zirconia-reinforced lithium silicate 9ZLS) ceramics by the computer-aided design and computer-aided manufacturing (CAD/CAM) technology.

Materials and Methods: In this in vitro experimental study, 24 extracted mandibular first molars received standard endocrown preparation and were randomly assigned to two groups ($n = 12$) for the fabrication of endocrowns with ZLS (Suprinity) and LDS (IPS e.max CAD) ceramics. After scanning the teeth with a CAD scanner, endocrowns were designed by inLab Software version 15 (inLab SW 15) and prepared by an imes-icore 350i milling machine. The vertical marginal gap of endocrowns was measured under a stereomicroscope at three steps before and after cementation and after thermomechanical cycles. The fracture resistance of specimens was then measured by load application at a 45° angle. Mode of failure was also determined as reparable or irreparable. Data were analyzed using Pearson's correlation test and *t*-test.

Results: The mean fracture resistance of ZLS endocrowns was significantly higher than that of LDS endocrowns ($P = 0.000$). The reparability of ZLS endocrowns was zero, while that of LDS endocrowns was 83.33 %. The vertical marginal gap was significantly smaller in ZLS than in LDS endocrowns at all three time points ($P < 0.05$). Also, the marginal gap increased by cementation and thermomechanical cycles in both groups.

Conclusion: ZLS and LDS endocrowns both showed acceptable vertical marginal adaptation. ZLS had superior marginal adaptation and higher fracture resistance.

1. Introduction

The prosthetic reconstruction of teeth post-endodontic treatment significantly impacts the clinical success of treatment (Taha et al., 2018). Preserving maximum tooth structure is crucial for enhancing fracture resistance and ensuring long-lasting clinical effectiveness of restorations, as tooth fracture often leads to extraction (Skalskyi et al., 2018; De Kuijper et al., 2019). Additionally, the poor marginal adaptation of restorations is a common cause of treatment failure, contributing to issues such as secondary caries and periodontal disease due to saliva and bacterial leakage (Taha et al., 2018).

Several methods have been proposed to reconstruct endodontically-treated teeth that have lost a significant part of their structure. The conventionally adopted methods (e.g., the metal post and core systems with extracoronal crowns) lead to a significant loss of tooth structure, i.e., 58.3 % (Biacchi et al., 2013; Dejak and Młotkowski, 2013). Therefore, they can weaken the root for the reconstruction of such teeth (Sedrez-Porto et al., 2019). Moreover, these methods require root canal flaring, heightening the risk of perforation in narrow or curved molar canals (Dejak and Młotkowski, 2013). The notable difference in elasticity between metal cores and natural dentin elevates the likelihood of root cracking and fracture. Furthermore, it adversely affects the coronal seal

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of root-filling materials (Hamdy, 2015).

Recent advances in adhesive systems have enabled the reconstruction of severely destructed posterior teeth with intracoronal restorations, known as endocrowns (Sedrez-Porto et al., 2019). The main advantages of endocrowns include the need for less preparation compared with post and core restorations and minimal invasion to the root canal system, optimal esthetics, superior mechanical properties, a faster fabrication process, and lower cost (Skalskyi et al., 2018). Studies have extensively documented excellent fracture resistance and mechanical performance of endocrowns, advocating for their use as a reliable method for reconstructing endodontically-treated teeth (Borgia Botto et al., 2016; Dejak and Młotkowski, 2013; Hamdy, 2015; Sedrez-Porto et al., 2019).

Endocrown material significantly impacts their durability and clinical performance (Sedrez-Porto et al., 2019). Zirconia endocrowns, for instance, demonstrated notably higher fracture resistance than IPS e.max counterparts (Skalskyi et al., 2018). Although zirconia endocrowns displayed greater resistance than LDS ones, they also showed a higher occurrence of irreparable fractures that might necessitate tooth extraction (Sedrez-Porto et al., 2019). IPS e.max endocrowns also had a higher frequency of catastrophic fracture involving the root(s), which is irreparable (Hamdy, 2015). In addition, IPS e.max Press and IPS e.max CAD endocrowns exhibit higher fracture strength than the Enamic, Feldspathic, and glass–ceramic-reinforced zirconia (Sağlam et al., 2021). ZLS endocrowns are also reported to have higher internal adaptation than translucent zircona (Amini et al., 2021).

Lithium disilicate is a widely utilized and extensively researched material for producing endocrowns. One of its primary benefits is its exceptional blend of aesthetic appeal and mechanical strength (Zardoni et al., 2023). However, studies comparing the marginal adaptation of LDS and zirconia-reinforced lithium silicate (ZLS) endocrowns are limited, and the available ones have reported contradictory results (Ji et al., 2015; Taha et al., 2018).

The present study compares IPS e.max LDS and Suprinity ZLS ceramic endocrowns in terms of fracture resistance and marginal adaptation. The first null hypothesis suggests no significant difference in fracture resistance between the endocrown types. The second null hypothesis proposes no notable variance in repairable and irreparable failure frequency. Finally, the third null hypothesis indicates no significant difference in the vertical marginal gap between the two endocrown types.

2. Materials and methods

This experimental in vitro study was conducted at Tehran Islamic Azad University, Iran, from February to August 2022. The study was approved by the ethics committee of the School of Dentistry, Islamic Azad University, Tehran (Iran).

The minimum sample size was calculated to be 10 in each group according to previous studies (Altier et al., 2018; Guo et al., 2016; Taha et al., 2018) assuming alpha = 0.05, beta = 0.2, effect size of 0.46, and standard deviation of 0.4 using the advanced repeated measures analysis of variance (ANOVA) power analysis feature of PASS 11.

2.1. Specimen preparation

A total of 24 periodontally hopeless mandibular first molars with two separate roots were selected for the study. Their mean mesiodistal width was measured at 11.01 ± 0.74 mm (mm), and the average buccolingual width was 10.37 ± 0.36 mm. Root length averaged 13.16 ± 1.70 mm, while isthmus width was standardized with an initial #15 K-file. These measurements were meticulously conducted by a trained examiner by calipers to ensure consistency and accuracy. Additionally, the teeth underwent inspection at x60 magnification using a magnifier by the same examiner to verify the absence of any structural defects.

Exclusion criteria involved the absence of cracks, fractures, abnormal morphology, previous endodontic treatment, or restorations. The teeth underwent meticulous cleaning with a low-speed handpiece and prophy paste. Dental calculus was removed using an ultrasonic scaler. Also, for disinfection, they were immersed in a 0.5 % chloramine T solution at 4℃ for up to three months.

The teeth were then randomly assigned to two groups to receive LDS (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein) or ZLS (Suprinity, Vita Zanhfabrik, Germany) endocrowns (n = 12 from each) (Table 1). They were cut horizontally at 1.5 mm above their cementoenamel junction by a diamond bur and then underwent endodontic treatment. Working length was determined using a #10 K-file 0.5 mm shorter than the apical foramen. The root canals were cleaned, shaped, and flared by the step-back technique up to file #50. After using each file, the root canals were rinsed with 1 % NaOCl, and recapitulation was performed. The root canals were then dried with paper points and filled with gutta-percha (4 % tapered; Diadent, Seoul, Korea) and AH-Plus sealer (Dentsply, Maillefer, USA) by cold lateral compaction technique. Excess material was removed 1 mm below the cementoenamel junction using a hot plugger.

The pulp chamber undercuts were then removed, and internal axial walls were prepared with an 8-10° taper with a round-end tapered diamond bur. The finish line was a circumferential butt joint with a width of 2 mm. The pulp chamber depth after preparation was 4 mm as measured by a periodontal probe (Figs. 1–3) After preparation of the endocrown cavity, the orifice of the canals was sealed with light-cure resin-modified glass ionomer (GL Resin CEM UF, Oxford, United Kingdom).

In the next step, the teeth were then scanned by a CAD extraoral scanner (Sirona inEos Blue, Wals, Germany). Afterward, anatomical endocrowns were designed by SW15 inLab software and fabricated by a milling machine (Imes-icore 350i milling machine). Before cementation, they were sintered in a furnace Aauto therm-100; Koushafan Pars, Iran) to facilitate crystallization. Table 2 presents the protocol of sintering for the two ceramic types. To ensure complete seating of endocrowns, a metal jig was designed before their cementation.

2.2. Measuring the marginal gap

The vertical marginal gap was measured under a stereomicroscope at x20 magnification (SZX12; Olympus, Japan). The tooth-restoration interface was photographed by a digital camera connected to the stereomicroscope (DP 72; Olympus, Japan). Vertical marginal gap was measured at 12 points of each endocrown (3 points on each surface) on the images using a computer program. The mean of the 12 values was calculated and reported in micrometers (μm) as the mean vertical marginal gap of each endocrown.

Following the manufacturer's instructions, both types of endocrowns underwent etching with 10 % hydrofluoric acid (Porcelain etch, Maquira, Brazil) for 20 s and rinsed with alcohol and air-dried. Silane (Porcelain Silane, Ultradent Products, USA) was applied for 60 s. Enamel

Table 1
Characteristics of ceramics used in current study.

Ceramic	Type	Composition (weight %)	Manufacturer
Suprinity LS	ZLS	SiO_2(56–64) Li_2O(15–21) ZrO_2(8–12) P_2O_5(3–8) K_2O(1–4) Al_2O_3(1–4)	Vita Zanhfabrik, Germany
IPS e.max CAD	LDS	SiO_2(57–80) Li_2O(11–19) K_2O(0–13) P_2O_5(0–11) ZrO_2(0–8) ZnO(0–8)	Ivoclar Vivadent Schaan, Lichtenstein

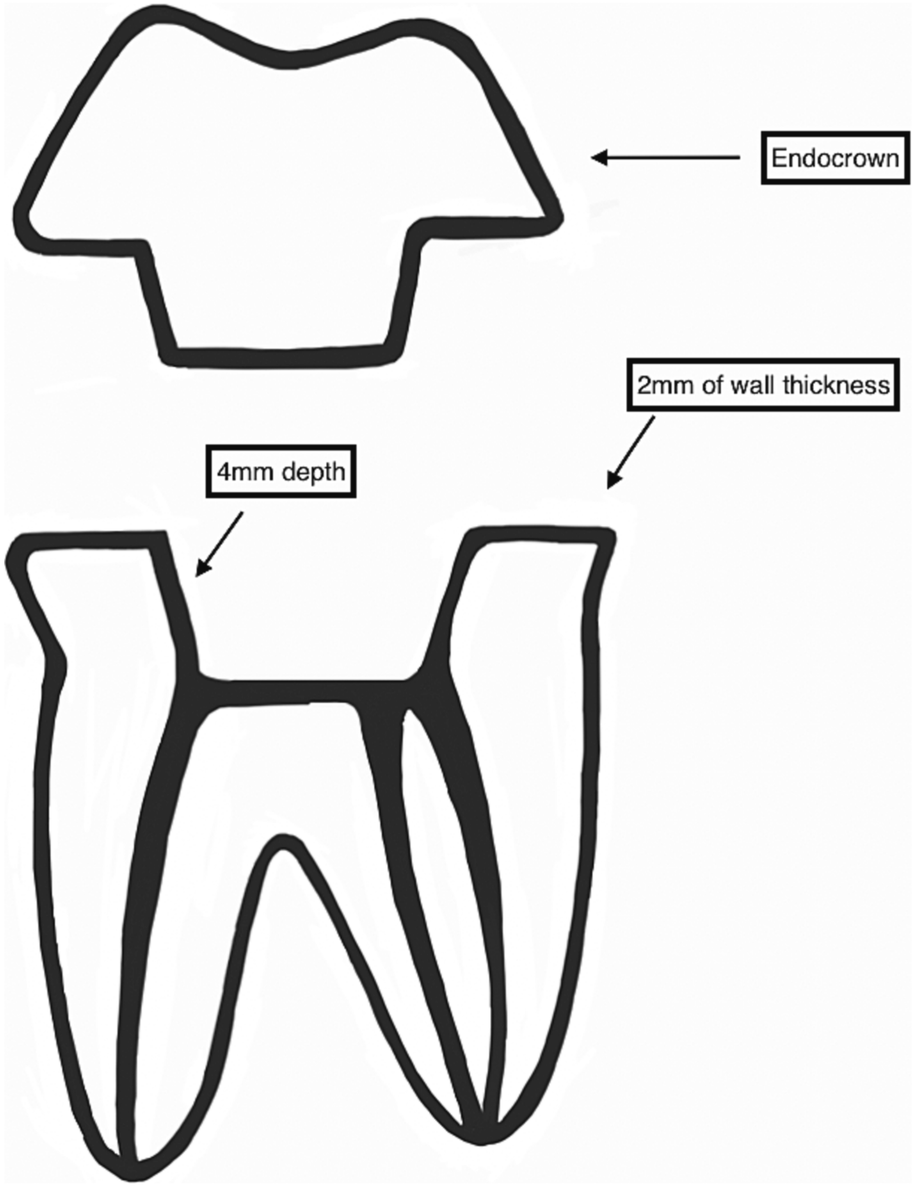

Fig. 1. Schematic view of prepared tooth for an endocrown restoration.

surfaces were etched with 37.5 % phosphoric acid gel (Maquira, Brazil) for 30 s, rinsed, and dried. Self-adhesive resin cement (SelfCem; Medicept, Switzerland) was applied, and the endocrown was seated with finger pressure for 10 min. After curing the cement for 2 s, excess cement was removed, and light-curing continued for 20 s on each surface. The vertical margin gap was re-measured at 12 points for each endocrown post-cementation.

The teeth then endured 5,000 thermal cycles, simulating 6 months of oral exposure (TC/300; Vafaei Industrial Factory, Iran). These cycles involved alternating temperatures between 5 and 55℃ with 30-s dwell times at each temperature and a transfer time of 30 s (lasting 90 min per cycle). Mechanical cycles included applying a 50 N load by a frequency of 6 x 10^5 cycles, corresponding to 6 months of mastication. The load was applied to the central fossa perpendicular to the occlusal surface in a CS-4 chewing simulator (SD Mechatronik, Feldkrichen, Westerham, Germany). After these cycles, the marginal gap was reevaluated, and all specimens were immersed in saline for 24 h at room temperature.

2.3. *Fracture resistance testing*

Each specimen's fracture resistance was assessed using a universal testing machine (Zwick, Germany). A stainless-steel ball applied load at a 45° angle to the central fossa of each endocrown, mimicking oral axial and lateral forces. Starting at 50 N, the crosshead speed was set at 0.5 mm/min, and the load was increased until fracture occurred. The force at the fracture point was measured in Newtons (N).

Based on the fracture line's position, teeth were sorted into repairable and irreparable fracture groups. Fractures stopping within 1 mm below the tooth-endocrine interface were considered repairable. Meanwhile, those surpassing this line (>1 mm) were categorized as irreparable.

2.4. *Statistical analysis*

Data distribution normality was evaluated by the Kolmogorov-Smirnov test. Also, the statistical analysis was performed using the SPSS software. Data were further analyzed using Pearson's correlation test and *t*-test to examine relationships and differences between

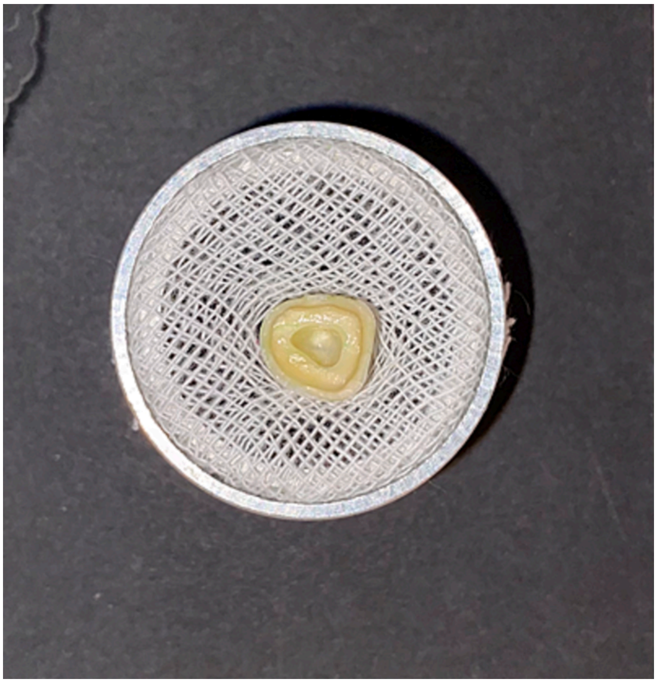

Fig. 2. Overall view of preparation.

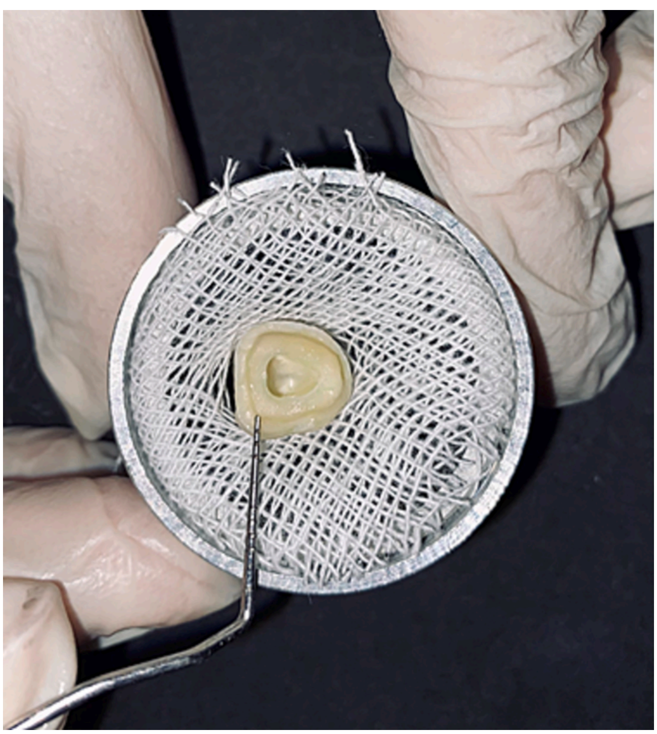

Fig. 3. Measuring the finish line width.

variables.

3. Results

3.1. Fracture resistance

Table 3 presents the mean fracture resistance of the two groups. Considering the normal distribution of data as confirmed by the Kolmogorov-Smirnov test ($P > 0.05$), a *t*-test was applied to compare the fracture resistance of the two groups. The results showed significantly higher fracture resistance of ZLS ceramic ($P = 0.000$).

Regarding the failure mode, the results showed that the reparability of Suprinity ZLS endocrowns was 0, while this rate was 83.33 % for IPS e.max LDS endocrowns.

3.2. Vertical marginal gap

Table 3 also presents the mean vertical marginal gap of the two groups measured at three different time points (T_0, T_1, and T_2). As can be seen, the mean vertical marginal gap was significantly smaller in Suprinity ZLS endocrowns than IPS e.max LDS endocrowns before cementation (T_0; $P = 0.006$), after cementation (T_1; $P = 0.022$), and after thermomechanical cycles (T_2; $P = 0.000$). In addition, the marginal gap significantly increased after cementation and after thermomechanical cycles in both groups ($P < 0.05$).

Overall, these results suggest that ZLS ceramic may provide advantages in terms of fracture resistance and marginal fit when compared to IPS e.max LDS ceramic in the given experimental setting.

4. Discussion

The present study compared IPS e.max LDS and Suprinity ZLS ceramic endocrowns for fracture resistance, mode of failure, and vertical marginal gap. Findings revealed that ZLS endocrowns had higher fracture resistance, smaller marginal gaps, and more irreparable failures than LDS endocrowns. All initial hypotheses were rejected based on these results.

In a study similar to the present research, Yildirim et al. (2017) compared IPS e.max and Suprinity Vita ceramic restorations. They observed larger marginal gaps in LDS compared to ZLS restorations; this result was consistent with those of the present study. However, their method was different as they assessed 20 points for the marginal gap and did not consider cementation or thermomechanical cycling.

Sağlam et al. (2021) compared the marginal gap of LDS and ZLS endocrowns fabricated for mandibular first molars with the CAD/CAM technology. They reported a significantly larger marginal gap of LDS than ZLS endocrowns. Their results were in line with the present findings. El Sayed and Emam (2019) compared the vertical marginal gap of LDS and ZLS endocrowns before and after mechanical cycles. They found no significant difference in the marginal gap between the two types of endocrowns; however, they showed that mechanical cycles significantly increased the marginal gap in both groups. Their results were different from those of the present findings in the first part, which may be due to methodological differences. Their preparation design (1.5 mm axial wall thickness, 2 mm occlusal surface thickness at the cusp tips, 1.5 mm occlusal surface thickness at the central fossa, and 50

Table 2
Protocol of sintering for the two ceramic types.

Ceramic type	Stand-by temperature °C))	Closing time (minutes)	Heating speed (°C/min)	Sintering temperature (°C)	Cooling time (minutes)	Vaccum (°C)
Suprinity	400	4	55	840	8	First time at 410 Second time at 840
IPS e.max CAD	403	6	90	820	7:10	First time at 550 Second time at 820

Table 3
Mean fracture resistance (N) and vertical marginal gap (μm) of the two groups.

Group	Marginal gap before cementation (T_0)		Marginal gap after cementation (T_1)		Marginal gap after thermomechanical cycles (T_2)		Fracture resistance	
	Mean	Std. deviation	Mean	Std. deviation	Mean	Std. deviation	Mean	Std. deviation
Suprinity	67.48	11.16	3.78	47.8	40.98	84.3	41.1444	72.46
IPS e.max CAD	43.78	13.30	95	89.21	77.107	38.19	66.1023	51.66

μm cement thickness), and type of finish line (chamfer) were different from those of the present study. Furthermore, they used a surveyor and marked some points with a marker so that they measured the marginal gap at the exact same points after cementation.

On the other hand, our results are different from those of El Ghoul et al. (2019), who compared LDS and ZLS endocrowns fabricated for mandibular molars. They reported a larger marginal gap in the ZLS group, although the difference did not reach statistical significance. Their results cannot be well compared with the present findings due to using a different type of scanner (an intraoral scanner), method of measurement (replica technique), and type of finish line.

Based on the current findings, ZLS endocrowns demonstrated notably higher fracture resistance than LDS endocrowns, yet all specimens exhibited irreparable failure. This issue challenges their viability as the primary choice for tooth reconstruction. Interestingly, both groups displayed a narrow and predictable range of behavior, indicated by their small standard deviations in fracture resistance within this study. However, further studies with a larger sample size are required to cast a final judgment regarding the failure mode.

Similarly, Sağlam et al. (2021) found increased fracture resistance in ZLS endocrowns. They noted that only 30 % of fractures were irreparable, with a higher occurrence in the ZLS group. However, they did not specify the frequency of mechanical cycles, and it seems they only applied a 10 kg load during the cement setting.

In another study, El Ghoul et al. (2019) reported significantly higher fracture resistance of ZLS endocrowns. Their results were in line with those of the present study, although they applied both axial and lateral loads to the specimens. Eisa et al. (2020) reported slightly, but not significantly, higher fracture resistance of Suprinity ZLS endocrowns compared with LDS endocrowns. All fractures were irreparable in their study in both groups. Nevertheless, they did not apply mechanical cycles, did not consider lateral forces, and had a small sample size.

A different perspective was presented by Hasanzade et al. (2020), suggesting that the type of restoration materials does not affect marginal discrepancy. One probable reason for this disparity is their omission of cementing the samples, a crucial step shown to increase marginal discrepancy. Sahebi et al. (2022) noted ZLS endocrowns with lower fracture strength but higher retention than zirconia crowns. While their study did not involve LDS, they found material selection significantly influenced both the retention and fracture strength of endocrowns.

Differences in study outcomes could stem from various factors: variations in the digital scanner and milling machine, distinctions in tooth preparation design (e.g., finish line type and width and pulp chamber depth), diverse endocrown materials, discrepancies in measurement tools and techniques, and variations in the precision levels of laboratory technicians.

The study had notable strengths, including consistent procedures conducted by a single operator and simulating real-world conditions through thermomechanical cycling and cementation. However, limitations such as a small sample size and an in vitro design restrict the generalizability of the findings. Future studies necessitate larger sample sizes and clinical trials for more dependable results. Additionally, further research should be conducted to explore the impact of finish line type, tooth type, and measurement methods on marginal gap results.

5. Conclusion

ZLS and LDS endocrowns had acceptable vertical marginal adaptation. ZLS endocrowns demonstrated higher fracture resistance and smaller gaps than LDS. However, larger samples and clinical trials are vital to confirm these results and evaluate long-term ZLS performance.

CRediT authorship contribution statement

Ezatollah Jalalian: Visualization, Supervision, Project administration, Funding acquisition. **Arash Zarbakhsh:** Visualization, Supervision, Project administration, Funding acquisition. **Sotude Khorshidi:** Writing – original draft, Formal analysis, Investigation. **Shaghayegh Golalipour:** Writing – original draft, Resources, Data curation. **Sara Mohammadnasl:** Conceptualization, Methodology, Software, Validation. **Maryam Sayyari:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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