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Marginal Fitness in Vertical and Horizontal Crown Preparations: A Comparative Analysis

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Abstract

Objectives: This study focused on comparing the marginal fit of crowns made of zirconia and lithium disilicate, using two types of preparation designs (vertical feather edge, horizontal shoulder) for both cemented and non-cemented situations. **Methods and Materials:** Forty maxillary premolars (all extracted) were randomly assigned to one of two groups based on material type: Lithium Disilicate (Group A) and Monolithic Zirconia (Group B). Within each of these groups, the teeth were further divided into two subgroups based on margin design: Feather Edge and Shoulder Preparation Designs (n=10). All specimens had standardized preparations performed with the aid of a modified dental surveyor, followed by digital scans. For the Crown (s) & Processes created by ExoCad and constructed via Pressing Technique (Lithium Disilicate) and Milling Technique (Zirconia), the preparation margins were evaluated pre -& Post Cementation via digital microscopy at 40x magnification at each Specimens Marked 16 Standardized locations using ImageJ Software. All standardized evaluations were subjected to: Two-Way ANOVA, Tukey HSD, AND Paired 't-test' statistical analyses. **Results:** After cementation all groups exhibited more of a marginal gap. The groups with vertical preparations A1 and B1 had a significantly less marginal gap compared to groups with horizontal preparations A2 and B2 prior to and following cementation. Group A1 had the least amount of gap and therefore exhibited a more favorable marginal adaptation of the lithium disilicate when using a vertical preparation than did groups A2, B1, and B2. There were significant differences between groups according to statistical analysis ($p < 0.05$). **Conclusion (Principal Designer):** The marginal adaptation of vertically prepared edges (feather edge/preparation) compared to horizontally prepared (shoulder) edges produced significant differences; this was regardless of which type or class of ceramic material used. The findings indicate that by using minimally invasive vertical preparation techniques; the longevity of restorations and their fit can be greatly enhanced.

Keywords: Marginal adaptation, vertical preparation, shoulder preparation, lithium disilicate, zirconia, crown.

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Introduction

In restorative dentistry, achieving an optimal marginal adaptation is a crucial factor for the long-term success of dental restorations, particularly for all-ceramic crowns. The marginal gap, defined as the perpendicular distance between the restoration margin and the prepared tooth, plays a significant role in determining the clinical performance of dental prostheses. Poor marginal adaptation can lead to a host of complications, including microleakage, cement dissolution, secondary caries, periodontal inflammation, and ultimately, restoration failure (Hasanzade, Aminikhah et al. 2021, Elsherbini, Al-Zordk et al. 2022). The tooth preparation design plays a pivotal role in this aspect, with two primary approaches being widely utilized: horizontal and vertical preparations. Each method offers distinct advantages and considerations that influence clinical outcomes.

Traditional horizontal preparations, such as chamfer and shoulder, have long been considered the gold standard due to their ability to provide a well-defined finish line, with better visibility on the impression and die and strong support for the restoration (Bonfanti-Gris, Pradies et al. 2024). However, these designs often require significant tooth structure removal, which can compromise the biological health of the tooth and increase the risk of pulp exposure (Wahsh and Taha 2020).

In contrast, vertical preparation designs, such as knife-edge or feather-edge, have gained popularity due to their minimally invasive nature. These designs preserve more tooth structure, particularly in the cervical area, and are believed to offer enhanced marginal fit and simplified impression-taking (Patroni, Chiodera et al. 2010, Di Febo, Bedendo et al. 2015).

However, concerns have been raised regarding the thinness of the margins in vertical preparations, which may predispose the restoration to fracture under occlusal loading (Findakly and Jasim 2019, Kasem, Sakrana et al. 2020).

Despite these concerns, several studies have reported encouraging clinical outcomes for restorations with vertical margins, suggesting that they may be a viable alternative to traditional horizontal preparations (Cortellini and Canale 2012, Schmitz, Cortellini et al. 2017).

The choice of restorative material also significantly influences marginal adaptation.

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Lithium disilicate and zirconia are two of the most commonly used materials in contemporary prosthodontics, each with distinct advantages and limitations. Lithium disilicate is famous for its excellent esthetic properties and acceptable mechanical strength, making it a popular choice for anterior restorations (Al-Dulaijan, Aljubran et al. 2023). However, its relatively lower fracture toughness compared to zirconia has raised concerns about its suitability for high-stress areas, particularly when used with thin margins (Fuzzi, TriCariCo et al. 2017). Zirconia, on the other hand, is known for its exceptional mechanical properties, including high fracture toughness and resistance to wear, making it ideal for posterior restorations (Özkurt-Kayahan 2016). However, its opacity can be a drawback in aesthetically demanding cases, and its bonding to tooth structure can be challenging without proper surface treatment (Akrawatcharawittaya, Sriamporn et al. 2024).

Recent advancements in material science and digital fabrication techniques have further complicated the decision-making process for clinicians. The introduction of translucent zirconia and high-strength lithium disilicate formulations has expanded the range of options available for both anterior and posterior restorations (Al-Haj Husain, Özcan et al. 2022, Kongkiatkamon, Rokaya et al. 2023). However, the impact of these materials on marginal adaptation, particularly in the context of different preparation designs, remains an area of active research. Studies have shown that the marginal fit of zirconia crowns can be influenced by factors such as the sintering process, surface treatment, and cementation protocol (Abdulazeez and Majeed 2021). Similarly, the marginal adaptation of lithium disilicate crowns has been found to vary depending on the fabrication method, with pressed crowns generally exhibiting a better fit than milled crowns (Sanches, Metzker et al. 2023).

Given the importance of marginal adaptation in the clinical success of dental restorations, further research is needed to evaluate the impact of different preparation designs and materials on marginal fit. This study aims to contribute to the growing body of literature by comparing the marginal adaptation of lithium disilicate and zirconia crowns fabricated using vertical and horizontal preparation designs. Examining the marginal gaps before and after cementation provides insights into the optimal preparation design and material combination for achieving superior marginal fit in all-ceramic restorations. The hypothesis was that there is a significant difference in the marginal adaptation of crowns fabricated using vertical versus horizontal preparation designs.

Materials and Methods

Human Research Ethical Committee, Mustansiriyah University's, College of Dentistry, approved the ethical clearance for the current study (Protocol Code: MUOPR29). The sample size was calculated using G* power software (version 3.1.9.7; Franz-Faul, University of Kiel, Germany) at 80% power level with 5% significance level. This method provided 80 % (Faul, Erdfelder et al. 2009) statistically robust sample sizes. We used 40 healthy maxillary premolars from patients that were to be removed for orthodontic reasons. All selected premolars had been cleaned and polished, followed by being washed with distilled water (Zheng, Cao et al. 2022). Only those teeth that displayed an unaltered oclusion anatomy, as well as having equal size crowns , were included in our study. In order to rule out any samples that had visible caries or cracks, sample evaluation was performed using a digital microscope (22x). Because of the high degree of sample variability, the study used a one-way ANOVA and found that size differences within the samples were less than 10% (El-Helali et al., 2013).

To avoid microbial as well as fungal contamination and to keep it preserved, the teeth were immersed in 0.1% thymol solution for 24 hours before being placed in deionized distilled water for future reference (Abdulazeez and Majeed 2021). In order to replicate the biological width, each tooth was marked with a horizontal line 2 mm below the CEJ (cemento-enamel junction). Each tooth was then mounted vertically via an adjustable arm of a modified dental surveyor manufactured by Saeshin in Daegu, Korea). The teeth were then embedded using self-cure acrylic resin (GC Pattern Resin manufactured by GC Corp., Japan) within custom fabricated teflon molds, which were 20 mm in diameter x 30 mm deep.

Teeth randomization and grouping

After selecting the teeth from the inclusion criteria, randomization was completed. Teeth were assigned a unique identifying number

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that was then entered into an Excel (Microsoft Corp., Redmond, WA, USA) column. The unique number assigned to each tooth was utilized to randomly generate a corresponding number using the Excel RAND function. The teeth were allocated to two main groups according to the material they were made from: Group A consisted of lithium-disilicate glass ceramic (IPS e.max CAD, Ivoclar Vivadent), and Group B consisted of monolithic zirconia crowns (IPS e.max ZirCAD prime; Ivoclar Vivadent). Each main group was then divided into two subgroups based on the type of preparation design that had been completed for each tooth: subgroups A1 and B1 contained teeth with feather-edge preparations, and subgroups A2 and B2 contained teeth with shoulder preparations (see Figure 1).

Prosthetic procedures

For standardization purposes, the same operator prepared all samples by utilizing a modified dental surveyor (Saeshin, Daegu, Korea). The surveyor's upper arm was adapted to hold a high-speed, water-cooled electric handpiece (Guilin Woodpecker Co., China). The acrylic block was fixed on the surveyor's horizontal table, aligning the bur's long axis with the tooth's long axis. This setup ensured a uniform bur taper along the tooth's axial wall (Ibraheem and Hmedat 2013). A permanent color marker was used to mark the future finish line position by drawing a line 1mm above CEJ, following the cervical line of the buccal side as a reference (Findakly and Jasim 2019). **Figure 2**

The vertical preparation was performed using a point safe-end tapered diamond stone (851012M-FG, NTI, Germany). This reduction was verified for each specimen using depth-orientation grooves and confirmed using a digital calliper with an accuracy of ±0.01 mm. The occlusal reduction was performed following the occlusal tooth anatomy with a 4 mm occlusal-cervical height and a total convergence angle of 4 degrees. To ensure accurate angulation, a protractor was mounted to the surveyor’s arm to align the bur's long axis with the tooth's long axis, allowing precise control of the axial wall inclination. The taper of the bur was validated to give both the intended 0.8 mm axial reduction and a 4° total convergence angle, consistently across all specimens. **Figure 3**

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For shoulder preparation, a flat-end tapered stone (847K-016M-FG, NTI, Germany) creates a 1.5 mm axial reduction, a 1 mm shoulder margin, and a 4 mm occlusal-cervical height with a total convergence of 6 degrees. A calibrated flat-end bur with a defined tip width was used to ensure a consistent 1 mm finish line across all specimens, verified under magnification and confirmed using a digital calliper.

Fabrication of the restorations

Digital impressions were created with a scanner (I700) using CAD software (Exocad V3.2) to produce three-dimensional (3D) images of each prepared tooth, following the guidelines provided. The restorations were then designed based on the measurements for the crowns, which could be feather edge or shoulder margin. Feather edge crowns will have 1.5 mm of thickness at the occlusal surface, 0.8 mm of thickness at the axial surface, and 0.3 mm of thickness at the margin. Shoulder margins will have 1.5 mm of thickness at the occlusal surface, 1.3 mm of thickness at the axial surface, and 0.8 mm of thickness at the margin.

Crowns were created in a Programmat P310 furnace from pressable lithium disilicate (IPS e.max ingots; Ivoclar) by placing multiple oxygen atmospheres of crystallized lithium disilicate at 840C for 20 minutes,then polished and glazed for use. The crown was made of Zirconia (IPS e.max ZirCAD prime; Ivoclar), which was produced dry milled with a 5-axis milling machine (In-Laboratory SX 900 pro; Arum Dentistry), and subsequently sintered in a high temp (Dekema 674i) temperature furnace. During sintering, the temperature was increased at a rate of 3-4C / hr to 1541C over 8 hours.

Restorations were treated before bonding by sandblasting with an air powered sand-blasting machine (Renfert, Germany) (Particle size: 50µm-alumina (Al_2O_3)) under 1 bar pressure) from 10mm away from the restoration for approximately 15 seconds at a 45 degree angle (i.e., so that the surfaces of the restorations were roughened) to allow them to adhere. (Nasir 2023).

Measurement of the marginal gap pre-cementation

The methodology for measuring the marginal gap was based on the definition established by Holmes et al, which described it as the "perpendicular distance from the edge of the restoration to the margin of the tooth preparation" (Holmes, Bayne et al. 1989). The measurements were conducted using a USB digital microscope (set to a fixed magnification of 40×) with an integrated camera (U500 Digital Microscope, Guangdong, China), combined with ImageJ software version 1.50i for detailed image analysis.

To ensure accuracy and reproducibility, each crown was positioned on its corresponding tooth using a standard static load of 5 kg (50 N), applied with a specially designed screw-holding device. This load was intended to mimic the seating force during crown cementation, replicating the average bite forces generated by the jaw (Mansi, Al-Shamma and Saleh 2024).

The imaging procedure involved positioning a 3 MP digital camera vertically, 2.5 cm away from the sample, with the lens axis aligned at a 90° angle to the light source. The illumination was provided by two adjustable LED lamps, with a color index of approximately 95%. High-resolution images were captured at a fixed magnification of 40x and transferred to a personal computer. **Figure 4.**

The measurement process began with identifying four standardized points on each specimen: mid-buccal, mid-mesial, mid-distal, and mid-palatal. Two of these points were located exactly at the center of each surface, while the other two were positioned 1 mm apart. These points were carefully marked using a permanent marker to ensure consistent and representative measurements across all surfaces of the crown. For each specimen, a total of 16 measurements were taken (4 points per surface × 4 surfaces) (Nasir 2023). The mean value of these 16 measurements was calculated to represent the pre-cementation marginal gap for each specimen, providing a reliable and standardized metric for comparison. **Figure 5**

To minimize variability and enhance the reliability of the data, all measurements were performed by a single operator. This approach eliminated inter-operator variability, which could otherwise introduce inconsistencies in the results. Additionally, each measurement was repeated three times to reduce random errors and ensure the precision of the recorded values (Nasir 2023).

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A critical aspect of the measurement process was the calibration of the digital microscope to ensure that the recorded values were accurate and standardized. To achieve this, a photograph of a 1-millimeter section of a ruler was captured using the digital microscope at the same magnification (40x) used for the marginal gap measurements. This calibration image served as a reference for converting pixel-based measurements to micrometers (µm), which are more clinically relevant units. The calibration image was then analyzed using ImageJ software, a widely used tool in scientific research for image processing and measurement. Within the software, a straight-line tool was used to draw a line corresponding to the known distance of 1 millimeter on the ruler. The "Analyze" function was selected from the main menu, and the "Set Scale" option was used to input the known distance (1000 µm for 1 mm). This calibration process allowed the software to automatically convert pixel measurements to micrometers, ensuring that all subsequent measurements were accurate and standardized.

Cementation

For lithium-disilicate crowns, the intaglio surface was treated with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds, rinsed, and dried. Subsequently, a single layer of silane coupling agent (Monobond N, Ivoclar Vivadent) was applied to the prepared surface and allowed to sit for one minute.

For zirconia groups, the crowns were immersed and cleaned in 96% ethanol using an ultrasonic cleaner for 5 minutes to remove the remnants from the air abrasion process. The crowns were then air-dried and cleaned with Ivoclean for 20 seconds. Then, the pre-treated surfaces of the restorations were primed with a thin coat of an MDP-containing monomer (Monobond Plus, Ivoclar Vivadent).

The crowns were then bonded to the teeth with dual-cure resin cement (Variolink II Esthetic DC, Ivoclar Vivadent). Each restoration was initially seated with gentle finger pressure to ensure proper adaptation. Immediately afterwards, the entire assembly was placed inside a custom-made loading device capable of applying a constant static load of 5 kg parallel to the long axis of the crown for 6 minutes**.** Excess cement was

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brushed away, and curing was applied for 20 seconds on all surfaces. All samples were stored in distilled water at 37°C for 24 hours.

Measurement of marginal gap post-cementation

Following the cementation process, the marginal gap was measured using the same protocol as described for the pre-cementation measurements. This ensured consistency in methodology and allowed for a direct comparison of the marginal fit before and after cementation.

Statistical analysis

Statistical analysis of the data was performed using SPSS software (Statistical Package for Social Sciences, version 25.0; IBM Corp., NY, USA). The normal distribution of the data was assessed using the Shapiro-Wilk test, and the significance of the mean fracture strength differences among the four subgroups was determined using a two-way ANOVA test. The Tukey HSD test was applied for multiple group comparisons.

Results

The Shapiro–Wilk test indicated that the data followed a normal distribution ($p > 0.05$). The descriptive statistics, including mean, standard deviation, minimum, and maximum values for the vertical gap before and after cementation, are summarized in **Table 1**.

For the vertical gap before cementation, Group A2 and Group B2 exhibit the largest mean values (around 38), indicating a greater initial marginal gap compared to Group A1 and Group B1.

For the vertical gap after cementation, the mean values for all groups increased. Groups A2 and B2 again show the largest mean values, while Group A1 and Group B1 have smaller means (around 27 and 32, respectively) (**Figure 6)**.

The standard deviations indicate that the data for Group B2 had the highest variability, both before and after cementation. The Two-Way ANOVA results showed a statistically significant difference in the vertical gap between the groups, both before cementation ($F = 282.32$, $p < 0.001$) and after cementation ($F = 296.67$, $p < 0.001$). These results indicate that the preparation design (Vertical vs. Horizontal) has a significant effect on the marginal gap both before and after cementation. However, the material type (Lithium vs. Zirconia) had

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a marginal effect after cementation but not before. Additionally, the interaction between preparation design and material type was not significant in either case. **(Tables 2 and 3).**

The Tukey HSD post-hoc test was conducted to further explore the significant differences between groups identified by the ANOVA. The results for the vertical gap before and after cementation are presented below **(Tables 4 and 5).** The paired t-test was used to compare the pre- and post-cementation marginal gap within each group. The results are summarized in **Table 6**.

The paired t-test results indicate a statistically significant difference between the pre- and post-cementation marginal gap in all four groups ($p < 0.05$). The t-statistics are negative, indicating that the marginal gap is significantly larger *after* cementation. Group 4 shows the largest t-statistic (in absolute value), suggesting the most substantial increase in marginal gap after cementation.

Discussion

One of the most important factors that contribute to the longevity of prosthetic restorations is their marginal fitness, both internally and externally. A good, accurate fit means the restoration sits snugly on the tooth without gaps. This enhances retention, reduces the chances of bacterial infiltration, and lowers the risk of decay or gum problems (Elalfy, Shetawey and Alassar 2024). Assessing the vertical marginal gap is widely regarded as one of the most reliable and clinically significant approaches for determining the fit of crown restorations (Wolfart, Wegner et al. 2003). Most researchers agreed that marginal gaps below 120 µm are clinically acceptable (Sumanth, Poovani and Sonnahalli 2020). In this study, human teeth were utilized as abutments due to their elastic properties, to facilitate adhesive cementation of the crowns, and to provide a more accurate simulation of clinical situations compared to other types of abutments (Chen et al. 2023).

Premolar teeth were chosen because of their simpler anatomical structure (simpler root and crown structure) compared to molars, and the frequent extraction of healthy premolars for orthodontic reasons makes them more accessible and easier to standardize in research. Additionally, their size and uniformity aid in creating consistent test samples (Fráter, Sáry et al. 2022).

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All preparation steps were conducted using a modified dental surveyor to standardize and reduce variables during preparation, including the design of the finish line, the degree of axial wall taper, and the path of insertion (Kocaağaoğlu, Kılınç and Albayrak 2017).

Both zirconia and lithium disilicate were chosen as the crown material when doing this study because they are becoming frequently used materials for dental prosthetics. Lithium disilicate is considered to provide good aesthetics and an appropriate amount of strength for anterior restorations. Zirconia has also exhibited biocompatibility and high fracture toughness.

In recent times, minimally invasive approaches have gained great popularity, including the use of feather edge finish lines; these techniques are performed with the intent of conserving as much tooth structure as possible while also preserving the structural integrity and durability of restorations (Alex 2019; Zarone, Di Mauro et al. 2019; Adabo, Longhini et al. 2023).

In the past, shoulder and chamfer finish lines were typically considered to be superior in terms of aesthetically pleasing restorations because they provide the best support for the restoration. Unfortunately, both of these techniques require a significant amount of tooth structure to be removed. As a result, the two methods need to be compared in order to provide an understanding of the relationship between tooth preservation and marginal fit (Findakly and Jasim 2019, Mugri, Dewan et al. 2023, Noè, Toffoli et al. 2023, Ashour, El-Kateb and Azer 2024).

Different methods have been employed to assess the marginal vertical gap: a direct optical method using a microscope, micro-ct, impression-made replicative technique, cross-section method and projective achieved by use of profile projectors (Sumanth, Poovani or Sonnahalli 2020). A digital microscope was used for evaluating both the marginal fit of restoration restoratives used in this study. Digital microscopes are useful in a non-destructive way because of their high degree of viewability and functionality. Therefore, they were selected to assess the fit between prosthetic restoration margins and their margins. In this way, digital microscopy is not only direct and does not result in the

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destruction of either a restoration specimen or its physical location, but they can be utilised within the scope of routine dental practices as well as being the primary documented form of measuring the vertical gap between restorations (Abdullah/Ibraheem 2017, Mahdi/Majeed 2019, Wahsh/Taha 2020), (Abdulazeez/Majeed 2021, Elalfy/Shetawey or Alassar 2024).

In this research, the magnification of 40x has been previously utilized in the research studies on the marginal dissimilarity of restorations due to its ability to maintain a greater range of sight while at the same time producing marginal dissimilarities (Dauti et al. 2016; Cvikl et al. 2016; Sumanth et al. 2020; Poovani et al. 2020; Sonnahalli et al. 2020; Elalfy et al. 2024; Shetawey et al. 2024; Alassar et al. 2024).

The results of the currently executed research study clearly support the hypothesis that there is a significant difference between vertical and horizontal preparation designs when comparing marginal fit. The research data analysed indicate that vertical preparations (feather-edge) have far fewer gaps around the margins than horizontal preparations (shoulder) prior to and following placement of either lithium disilicate or zirconia crowns. This can be attributed to the following reasons: The vertical margins generate a thinner restoration edge (more acute angle), eliminating excess material bulk that often accumulates in shoulder margins and interferes with fit. The thinner the edge, the lesser the distance between the crown margin and the tooth (Shillingburg, Hobo et al. 1997, El Eneen, El-Naggar and Taymour 2019, Fahmy, Katamish et al. 2022). In addition, the simplified geometry of vertical margins with no defined horizontal steps provided a continuous axial surface for the restoration to seat against. The absence of a sharp finish line minimized fabrication complexity (over- or under-milling, particularly when using CAD/CAM technology), thus minimizing the risk of misfit (Cetik, Bahrami et al. 2017). Furthermore, The smoother margin design also facilitates easier scanning and digital design, resulting in more accurate crown fabrication and reduced discrepancies between the prepared tooth and the restoration margin (Gunel, Guncu et al. 2023, Zhou, Chen et al. 2025).

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Post-cementation measurements revealed an increase in marginal gap across all groups, a phenomenon attributed to cement layer thickness, hydraulic pressure from trapped air or excess cement and polymerization dynamics, as similarly observed in previous studies (Abdullah and Ibraheem 2017, El Eneen, El-Naggar and Taymour 2019, Abdulla and Majeed 2020). Notably, the increase was more pronounced in horizontal zirconia crowns (B2), indicating potential challenges in seating restorations with thick marginal configurations. In contrast, other studies have shown that cementation did not significantly affect the vertical marginal discrepancy of zirconia crowns (Gonzalo, Suárez et al. 2009, El-Dessouky, Salama et al. 2015). These conflicting results may be due to differences in factors such as the cement material, cement space, and seating force applied during cementation.

Although zirconia is well-regarded for its mechanical resilience, the results suggest that marginal adaptation may be less predictable compared to lithium disilicate, particularly in shoulder preparations. This variability may stem from factors such as the sintering process and surface treatment sensitivity, which are known to affect zirconia's marginal behavior (Kongkiatkamon, Rokaya et al. 2023). In contrast, the press technique used for lithium disilicate likely contributed to the improved fit observed in this group, aligning with the findings of Sanches et al. (2023) (Sanches, Metzker et al. 2023) that pressed lithium disilicate demonstrates superior marginal adaptation compared to milled alternatives.

These findings align with the observations of Comlekoglu et al. (2009) (Comlekoglu, Dundar et al. 2009), who found that zirconia copings designed with feather-edge margins exhibited smaller marginal discrepancies and marginal openings compared to those prepared with chamfer margins. Conversely, the study conducted by Cetik et al. (2017) (Cetik, Bahrami et al. 2017) using scanning electron microscopy (SEM) demonstrated that both chamfer and knife-edge preparations achieved similar levels of internal and marginal adaptation, with superior results when compared to shoulder margin designs.

Importantly, all groups demonstrated mean marginal gaps well below the 100 µm threshold considered clinically acceptable. This reinforces the efficacy of digital workflows in producing restorations with precise adaptation. From a clinical standpoint, the results advocate for the incorporation of vertical preparations in routine practice, particularly when esthetic demands and tissue preservation are paramount. However, the increased post-cementation discrepancies highlight the necessity of optimizing cementation techniques to mitigate marginal distortion.

Limitations of the study

This study was conducted under controlled in vitro conditions, which may not fully replicate the complexities of the oral environment, such as saliva, temperature variations, and occlusal forces over time. Only maxillary premolars were used, limiting the generalizability of the findings to other tooth types. The sample size, while statistically adequate, was relatively small.

Conclusion

Feather-edge design yields a larger amount of marginal adaptation compared with shoulder design regardless of materials used. Nevertheless, all the tested groups would be clinically acceptable following cementation.Future studies must be conducted to evaluate whether these results are replicable with similar findings across other clinical settings.

Conflict of interest

The authors reported that they have no conflicts of interest.

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Table 1: Descriptive statistics of the vertical marginal gap in (μm) before and after cementation for the four groups.

Group	**Before Cementation**				**After Cementation**			
	Min	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
A1	17.584	23.491	20.193	1.848	24.584	30.491	27.493	1.721
A2	33.856	44.088	38.637	3.408	46.975	55.288	50.943	2.890
B1	15.354	27.075	21.324	3.667	28.000	36.075	32.023	2.508
B2	29.945	49.887	38.624	6.163	41.145	61.251	51.252	6.761

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Table 2: Two-way ANOVA Results for comparison of the marginal Gap Before Cementation

Variable	df	Sum of Squares	Mean Square	F-value	p-value
Preparation Design	1	3345.42	3345.42	234.86	<0.001
Material Type	1	8.19	8.19	0.57	0.453
Interaction (Preparation Design × Material Type)	1	0.23	0.23	0.02	0.899
Residual	36	512.79	14.24	-	-

Table 3: Two-way ANOVA results for comparison of the marginal Gap after Cementation

Variable	df	Sum of Squares	Mean Square	F-value	p-value
Preparation Design	1	4661.02	4661.02	303.98	<0.001
Material Type	1	47.08	47.08	3.07	0.088
Interaction (Preparation Design × Material Type)	1	34.61	34.61	2.26	0.142
Residual	36	551.99	15.33	-	-

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Table 4: Tukey HSD Post-Hoc Test Results for multiple comparisons between different groups before cementation.

Group Comparison	Mean Difference (µm)	p-value	Significant?	95% Confidence Interval
A1 vs. A2	-18.44	<0.001	Yes	(-23.44, -13.44)
A1 vs. B1	-1.13	0.787	No	(-6.13, 3.87)
A1 vs. B2	-18.43	<0.001	Yes	(-23.43, -13.43)
A2 vs. B1	17.31	<0.001	Yes	(12.31, 22.31)
A2 vs. B2	0.01	1.000	No	(-4.99, 5.01)
B1 vs. B2	-17.30	<0.001	Yes	(-22.30, -12.30)

Table 5: Tukey HSD Post-Hoc Test Results for multiple comparisons between different groups after cementation.

Group Comparison	Mean Difference (µm)	p-value	Significant?	95% Confidence Interval
A1 vs. A2	-23.45	<0.001	Yes	(-28.24, -18.66)
A1 vs. B1	-4.53	0.070	No	(-9.32, 0.26)
A1 vs. B2	-23.76	<0.001	Yes	(-28.55, -18.97)
A2 vs. B1	18.92	<0.001	Yes	(14.13, 23.71)
A2 vs. B2	-0.31	0.998	No	(-5.10, 4.48)
B1 vs. B2	-19.23	<0.001	Yes	(-24.02, -14.44)

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Table 6: Paired t-test results for each group Pre- vs. Post-Cementation

Groups	Mean Pre-Cem	Mean Post-Cem	Mean Difference (Post-Pre)	df	p-value	95% CI of Difference	Significant?
A1	20.19	27.49	+7.30	9	<0.001	(6.08, 8.52)	Yes
A2	38.64	50.94	+12.30	9	<0.001	(10.42, 14.18)	Yes
B1	21.32	32.02	+10.70	9	<0.001	(8.55, 12.85)	Yes
B2	38.62	51.25	+12.63	9	<0.001	(9.45, 15.81)	Yes

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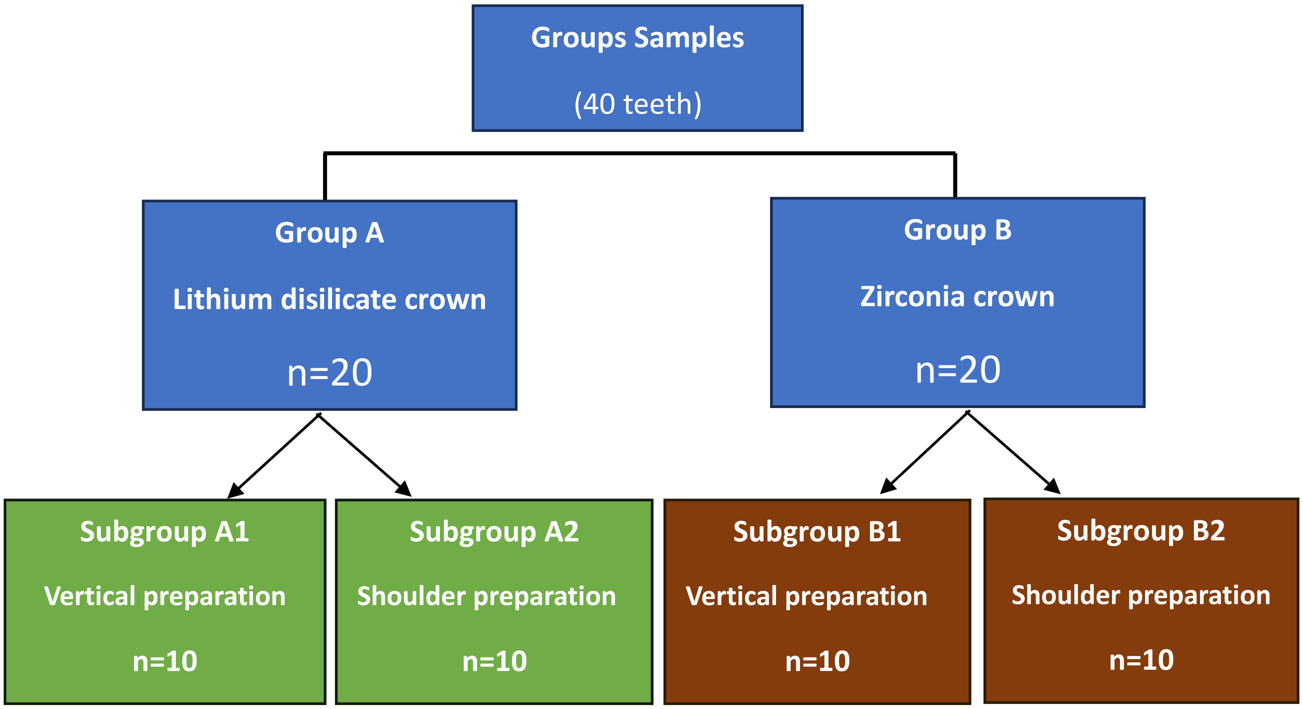

Figure 1: Sample distribution

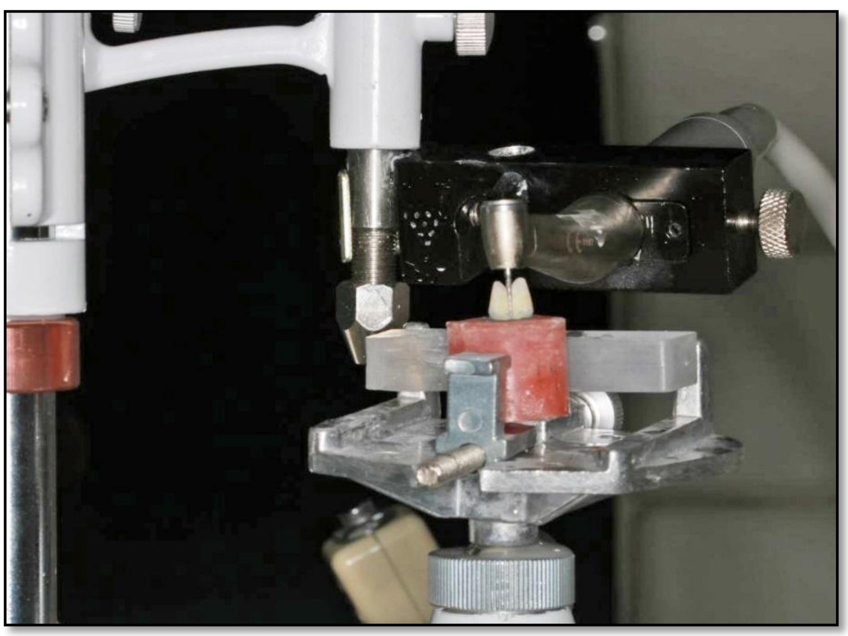

Figure 2: The modified dental surveyor

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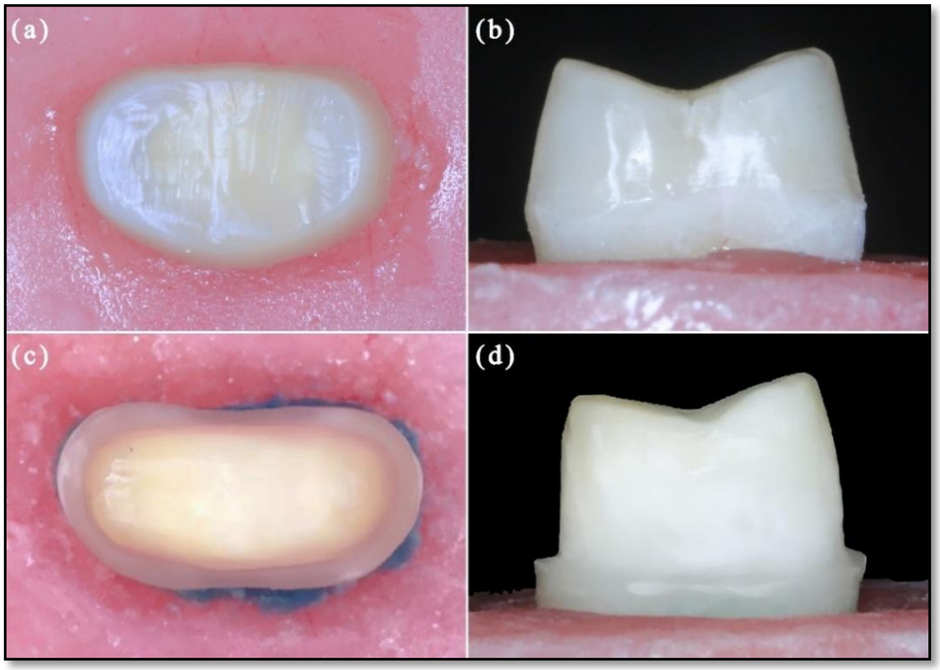

Figure 3: Preparation designs of this study; vertical preparation (a and b), and horizontal preparation (c and d).

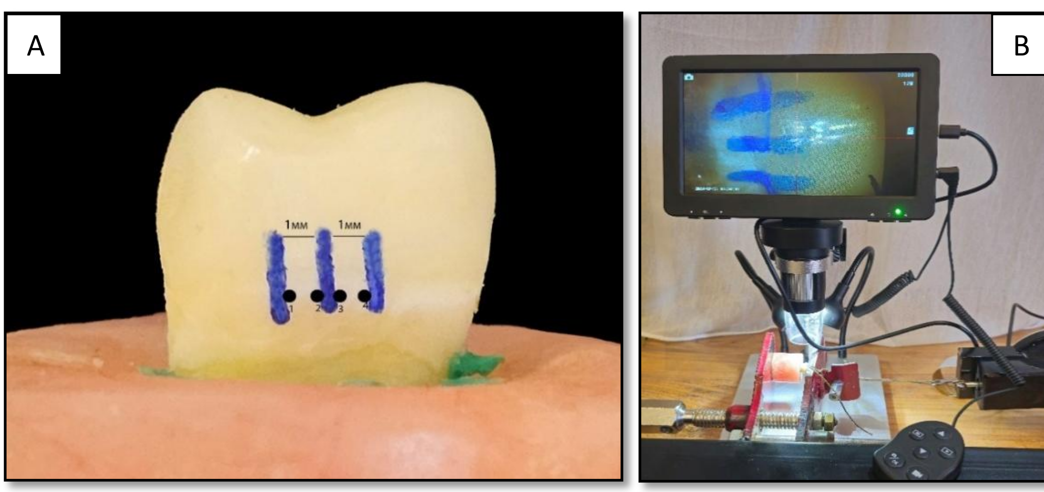

Figure 4: Marginal gap measurement (A): measurement Points. (B): 40x Digital microscope.

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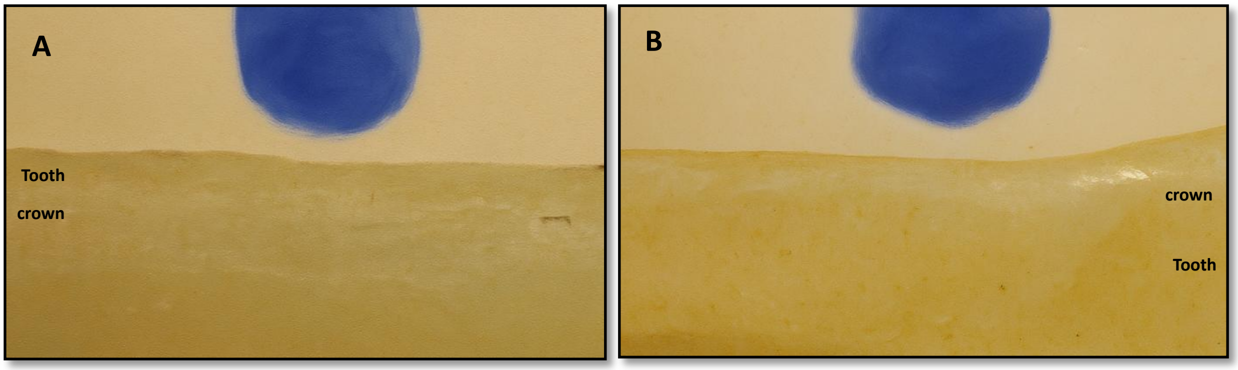

Figure 5: Digital microscopic image for a marginal gap of (A) feather edge design, (B) shoulder design.

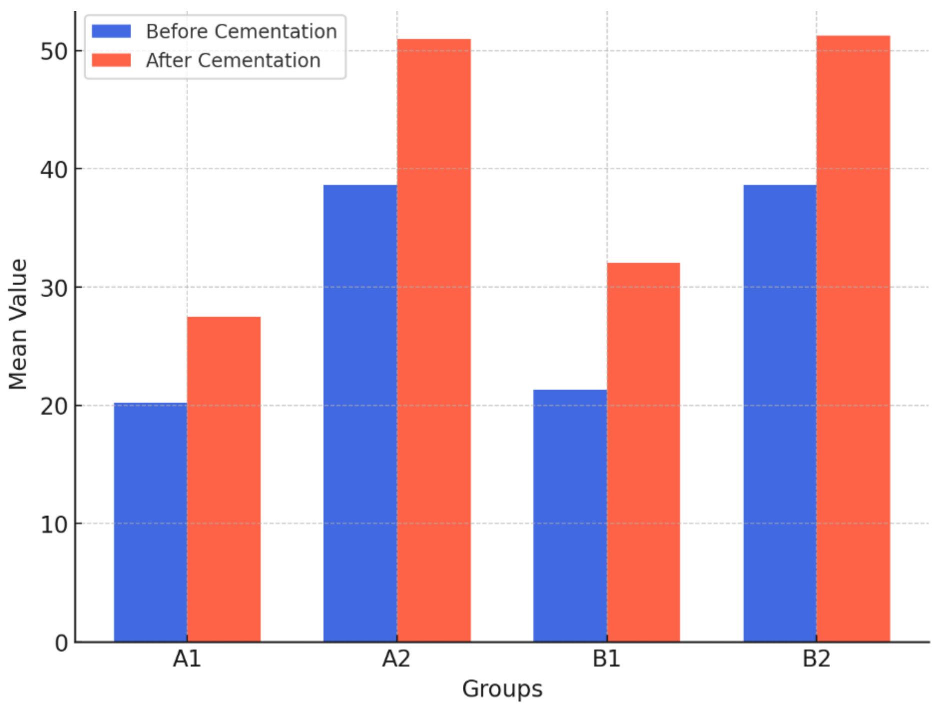

Figure 6: Bar chart showing the mean values of the marginal gap in (µm) of the four groups pre- and post-cementation.