The Effect of Preparation Design on The Marginal Adaptation of Monolithic Crowns Made of New CAD/CAM Ceramic Material. An In-Vitro Study

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Abstract:

Aim: This study endeavors to evaluate how various finish line designs impact the marginal adaptation of all-ceramic crowns, which are fabricated using advanced lithium disilicate CAD/CAM material before and after a thermocycling process. **Materials and methods:** Twenty - Seven human maxillary first premolar teeth were selected for the present study, and they were categorized into three groups, each comprising nine teeth: Group 1 ***(DCh)*** featuring a deep chamfer margin design measuring 1mm, Group 2 ***(Ch)*** with a chamfer margin design measuring 0.5mm, and Group 3 ***(Verti)*** exhibiting a feather-edge margin design measuring 0.2mm. The crowns were constructed from advanced lithium disilicate glass ceramic material. For the cementation process, an adhesive resin cement was utilized to cement the fabricated crowns to their respective teeth. After cementation precise measurements of the marginal discrepancy were taken both before and after the specimens were subjected to thermocycling. To analyze the data, statistical methods such as analysis of variance (ANOVA) and Tukey's post-hoc test, significant difference at ($P < 0.05$) were used. **Results:** Before and after undergoing thermocycling, it was observed that the ***DCh group*** exhibited the highest mean marginal gap values (64.67 µm, 71.08 µm). This was followed by the ***Ch group*** (52.40 µm, 61.98 µm), whereas the ***Verti group*** displayed the lowest mean marginal gap values (41.74 µm, 44.86 µm). This disparity was statistically significant, as evidenced by the one-way ANOVA test results. ($p =0.002<0.05$). Upon employing the pair-wise Tukey's post-hoc test, the distinctions between the ***DCh group*** and the ***Ch group*** were found to be insignificance ($p > 0.05$). **Conclusion:** Considering the constraints inherent to this study, when compared to the other groups, the ***Verti group*** demonstrated significantly superior marginal adaptation both before and after the thermal aging process.

KEY WORDS: Advanced lithium disilicate, digital dentistry, All ceramic crown, Vertical preparation, Marginal adaptation, Preparation design.

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Introduction:

Presently, dentists face the task of attaining excellent esthetic outcomes while minimizing the removal of natural dental structures. Thanks to digital dentistry, clinicians and technicians now have access to a wide range of materials and techniques, allowing them to achieve harmonious aesthetics and functionality with greater simplicity and conservation. With the advent of advanced all-ceramic materials and adhesive systems, there is now the possibility of preserving more vital tooth structure, particularly in the context of single tooth restorations.[1, 2]

Chairside dentistry has grown in popularity as a treatment option since the incorporation of CAD-CAM technologies into dental practice. Dental technology advancements have resulted in a diverse range of restorative materials, most notably dental ceramics, owing to the integration of (CAD-CAM) technologies.[3] Over the past few years, a discernible trend has emerged favoring the adoption of monolithic restorations as an alternative strategy aimed at diminishing the likelihood of chipping in veneering ceramics applied onto oxide ceramic frameworks. The creation of monolithic crowns utilizing silicate or oxide ceramics has been undertaken to achieve this objective.[4] Within the realm of dental ceramics, glass-matrix ceramics stand out with notable benefits in biocompatibility and translucency. Nonetheless, their inherent fragility prompted the integration of reinforcements to bolster their structural attributes. This innovation paved the way for the emergence of lithium disilicate glass ceramic (LDS) constructed by CAD/CAM during the early 2000s, marking a pivotal juncture in the evolution of restorative dentistry.[5, 6]

Regardless of the reality that lithium disilicate glass ceramic has grown in popularity and has replaced other glass-matrix ceramics as the material of choice, new materials are being marketed. Advanced lithium disilicate glass ceramic (ALDS) is a newer restorative material of glass-matrix ceramics that contains lithium aluminum silicate crystals called virgilite in its glassy zirconia matrix.[7] According to the manufacturer's specifications, the material's matrix firing process results in the formation of new virgilite crystals, which increases the overall strength of the structure. This results in a remarkable biaxial strength of more than 700 MPa, as well as significant improvements in optical and aesthetic properties. The significantly reduced firing time of only 4 minutes and 30 seconds is a significant advantage of Advanced Lithium Disilicate (ALDS), which is especially beneficial when using the appropriate induction chairside furnace.[8]

When getting ready to prepare dental abutment to receive a Fixed Partial Dentures (FPDs), dentists commonly define a finish line on the tooth's exterior where the restoration will eventually sit. These finish lines can be grouped into two main categories: supragingival, positioned above the gum line, or subgingival, located beneath the gum line. The latter carries a higher risk of provoking gingival inflammation. In addition to their position relative to the gums, these finish lines are also classified into two distinct types: horizontal finish lines, which consist of chamfer and shoulder designs, and vertical finish lines, which encompass feather or knife-edge margins.[9-12] The choice of a specific finish line is guided by numerous factors, like the tooth's location, inclination, the vitality of the pulp, the patient's age, the material used for the restoration, crown convexity, and the size of such a structure. It's worth noting that in certain clinical scenarios, the determination of the preparation and/or reconstruction approach is made during the procedure itself.[13]

The space between the finish line and the crown margin is denoted as marginal adaptation, which is considered a pivotal element significantly impacting the enduring success of a ceramic restoration.[14, 15] Extensive research has elucidated that marginal gap measurements falling within the range of 100 to 200 µm are widely deemed clinically satisfactory for cemented restorations.[16, 17] When a notable space exists between the margin of a restoration and the tooth's finishing line, the luting cement material becomes susceptible to contact with the oral environment. This interaction can trigger cement degradation and minute seepage, culminating in potential issues like secondary carries, irritation of the periodontal tissue, and, eventually, failure of the prosthetic restoration. It emphasizes the significance of precise marginal adaptation in ensuring the longevity and success of the dental restoration.[15, 18, 19] Marginal gap values have previously been measured using various devices such as the cross-sectioning technique; the impression replica technique; optical microscopes; radiographic techniques; scanning electron microscopes (SEM); stereomicroscopes; and micro-CT. [15, 17, 20-22]

Thermal ageing is a current method for accelerating the ageing of ceramics by simulating the oral environment to some extent.[23] For several cycles, The procedure encompasses standardized thermal variations with bath temperatures ranging from 5 to 55 degrees Celsius. Thermal ageing may estimate a restoration's longevity and be used for simulating the clinical behavior of the all ceramic material.[24]

The primary aim of this study conducted in a laboratory setting was to investigate the impact of different finish line designs on the marginal adaptation of all-ceramic crowns constructed from advanced lithium disilicate CAD/CAM material. The investigation encompassed both pre- and post-thermocycling scenarios. Two null hypotheses were formulated for this research endeavor. The 1st hypothesis suggested that there would be no significant variations in the marginal adaptation of advanced lithium disilicate crowns when employing different finish line designs. The 2nd null hypothesis proposed that subjecting these crowns to thermal aging would not induce any significant changes in their marginal fit, regardless of the specific finish line designs employed. Through rigorous testing and meticulous analysis, the study aimed to provide valuable insights into the behavior of this dental ceramic material under diverse preparation designs and thermal stresses.

Material and methods:

The present study was registered and approved by Institutional Review Board Organization IORG0010868, Ahram Canadian University's Faculty of Oral & Dental Medicine. (Approval Number: IRB00012891 #43).

The material used in this study was CEREC Tessera (advanced lithium disilicate glass-ceramic, ALDS) as described in table (1).[25]

Material	Chemical composition wt. %	Manufacture
CEREC Tessera (Advanced lithium disilicate glass-ceramic, ALDS)	The composition of CEREC Tessera includes 90% $Li_2Si_2O_5$, 5% Li_3PO_4, and 5% $Li_{0.5}Al_{0.5}Si_{2.5}O_6$ (Virgilite).	Dentsply Sirona, York, PA, USA

Table (1) chemical composition and manufacture of the material used in the present study:

Teeth preparation:

Twenty- Seven extracted healthy human maxillary first premolars were collected for the existing study. To remove any deposits, teeth were ultrasonically cleaned, with a copious amount of water to prevent the formation of any microcracks. A digital caliper was used to measure all the teeth. (Total Digital Caliper, Mallinro UPC: TMT32150, 6925582171563, Kerala, India), the selected teeth should have normal and comparable crown dimensions with normal occlusal anatomy. No caries, cracks, or restorations were observed as seen and checked with a computerized stereomicroscope (Microware, Hong Kong), any tooth with deficiencies was excluded. Subsequently, the teeth were placed in a solution of 0.1% thymol for a period of seven days at room temperature, effectively thwarting any potential fungal or bacterial growth. For the next phase, every individual tooth was carefully inserted into a specially crafted circular and hollow flexible mold. This mold was then filled with cold cured acrylic material (Acrostone, ISO; 113485, 2016) and meticulously aligned with the tooth's long axis, ensuring it resided within a 2 mm proximity to the Cementoenamel Junction (CEJ). The precise alignment aimed to replicate the natural biological width accurately. [15, 26]

Sample grouping

Twenty-seven maxillary premolar teeth were randomly divided into three groups (n = 9), corresponding to the finish line design:

• ***Group1: Deep chamfer (DCh)***

With margin design 1.0 mm in depth, round-end tapered diamond stone was used for preparation of axial wall, (green ring for preparation and yellow ring for finishing) (Komet Dental, Germany)

•**Group 2: *Chamfer* (*Ch)***

With margin design 0.5 mm in depth, round-end tapered diamond stone was used for preparation of axial wall, (green ring for preparation and yellow ring for finishing) (Komet Dental, Germany)

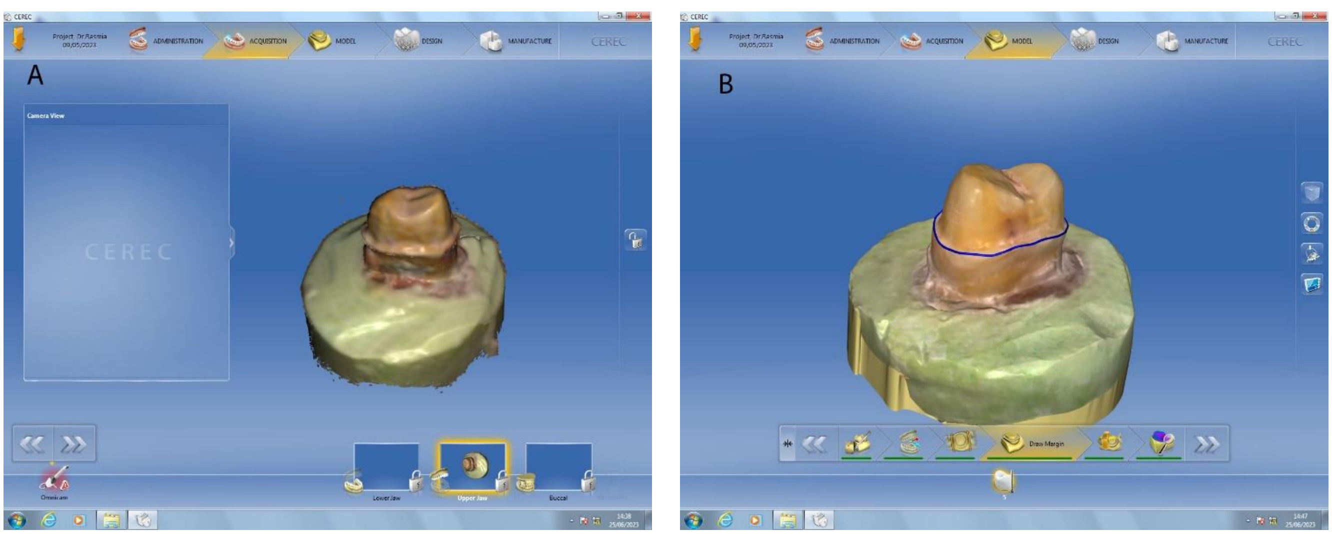
•***Group 3: Feather edge preparation (Verti)***

With vertical margin design 0.2 mm, long cylindrical flame diamond stone was used, (green ring for preparation and yellow ring for finishing) (INTENSIV, SKU: IT20705)

For all teeth samples, occlusal reduction of a 1 mm using a flame-shaped diamond stone and axial reduction of a 1 mm with a total convergence of 6° were performed. (26) To ensure standardization, tooth preparation was carried out by a well-trained single operator employing the PREP-CHECK feature within the CEREC 3D software version 4.2 (Sirona Dental Systems GmbH, Bensheim, Germany).

All ceramic crown fabrication:

Following the manufacturer's instructions, twenty-seven all-ceramic crowns were meticulously fabricated using advanced lithium disilicate CAD/CAM ceramic material (CEREC Tessera, Dentsply Sirona, York, PA, USA), as detailed in Table (1). The CAD/CAM system employed for this procedure was the CEREC AC CAD/CAM system, complemented by the Omnicam intraoral scanner manufactured by Dentsply Sirona GmbH, Bensheim, Germany. The scanning stage involved scanning each prepared tooth using the Omnicam intraoral scanner. Subsequently, the design phase entailed the creation of the all-ceramic crown, executed through the utilization of CEREC 3D software version 4.2, as shown in Figure (1). The software's biogeneric reference capability ensured that all crowns had standardized design of the restorations with consistent anatomy of the occlusal surface and occluso-gingival height. The MCXL 4-axis (Dentsply Sirona in Bensheim, Germany) wet milling and grinding machine was used for constructing the restorations. Sprues were cut after the milling process. The milled ALDs specimens (CEREC Tessera) were finished and polished per the manufacturer's instructions before being glazed in the ceramic furnace from Ivoclar Vivadent (Programat P310, Ivoclar Vivadent Inc., New York, USA) in accordance with the manufacturer's guidelines. Finally, the occlusal and margin thicknesses of each crown were carefully assessed using a digital caliper to ensure accuracy. (15)



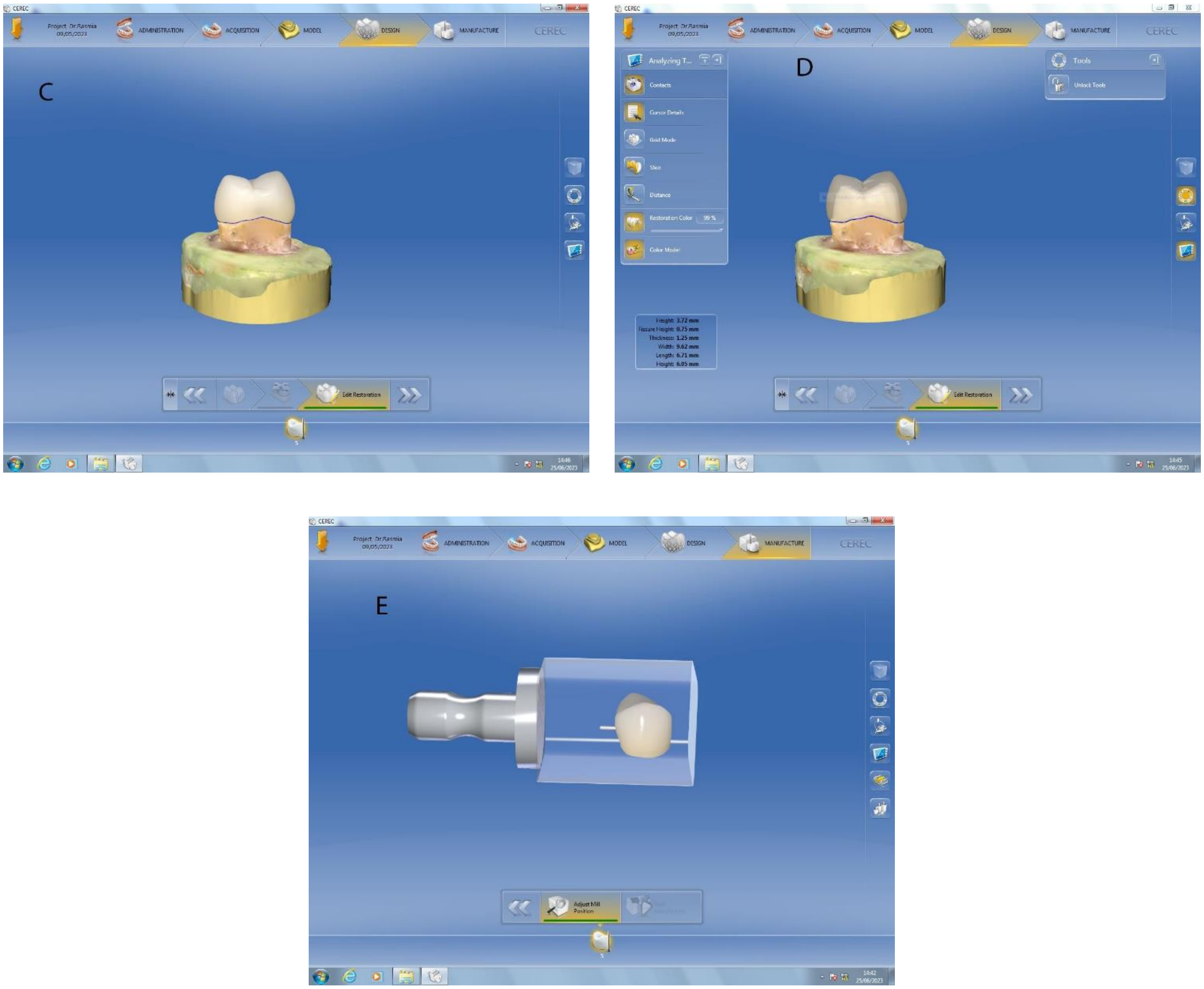


Figure (1): Fabrication of CAD/CAM crowns using CEREC AC system; A) Scanning the preparation, B) margin detection, C) &D) Designing the crowns using the CEREC 3D software, D) Manufacturing the restoration.

Bonding of all ceramic crowns

The interior surfaces of the ALDs crowns were treated for 30 seconds with a 9% hydrofluoric acid gel (Waldent porcelain etch, New Delhi, India), then thoroughly rinsed with distilled water. After 1 minute of drying, the restored surfaces were treated with a silane coupling agent (Porcelain Primer Bis-silane, BISCO-USA). After a meticulous cleaning with pumice on a low-speed rotary brush, the tooth underwent rinsing and drying prior to the application of two coats of bonding agent (All-Bond Universal, BISCO-USA) using a micro brush. The bonding agent was thinned with air and then cured with light cure for a duration of 20 seconds. Dual-cured adhesive resin cement (Han, Handae, Korea) was utilized to cement all the crowns onto their respective teeth. A 5-minute static load, vertically applied by a specially designed loading device with a force of 50 N, was then imposed on the crowns.

Following this, the crowns underwent a 2-second light curing process, and any excess cement was carefully eradicated with a scaler. Further curing with light for 20 seconds was performed on each side. Following cementation, the teeth were submerged in a water beaker containing distilled water for 24 hours at 37°C.

Following that, all specimens were thermocycled 2500 times to simulate three months of clinical use. Each water bath had a dwell time of 25 seconds, along with a 10-second lag time, temperatures ranged from a minimum of 5°C to a maximum of 55°C, this comprehensive process allowed for the evaluation of the restorations' durability and performance under real clinical conditions.[2, 15, 26-29]

Assessing the vertical Marginal Gap:

After the cementation process, every sample was captured under a consistent magnification of 110X through the utilization of a Digital Microscope (Scope Capture Digital Microscope, Guangdong, China) equipped with an integrated camera, following this, a digital image analysis tool (Image J 1.43U, National Institute of Health, USA) was employed to systematically assess and measure the space existing between the crown's margins and the finishing line of the prepared tooth. The morphometric measurements were taken at four different locations along the crown's four axial walls: buccal, distal, mesial, and lingual. Four equidistant points along the cervical circumference were measured at each of these predetermined locations, yielding a total of sixteen readings for each specimen. Following thermal ageing, these steps would be repeated. The average vertical gap for each crown was computed in micrometers (µm).[2, 15, 18, 30, 31] Figure (2&3&4)

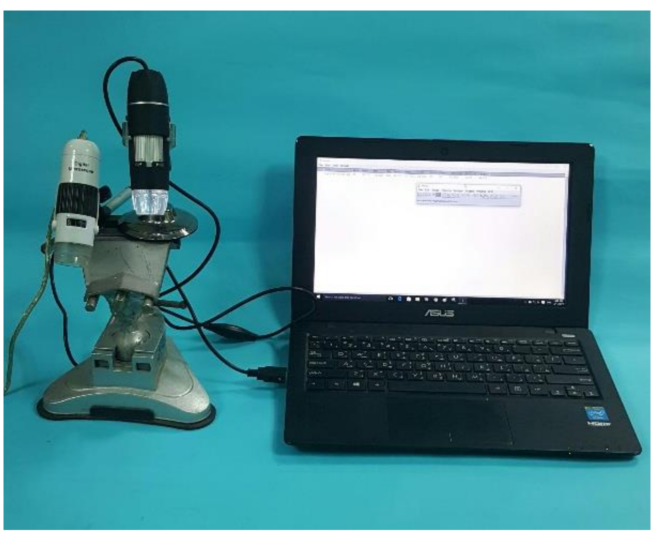


Figure (2): Showing the digital microscope.

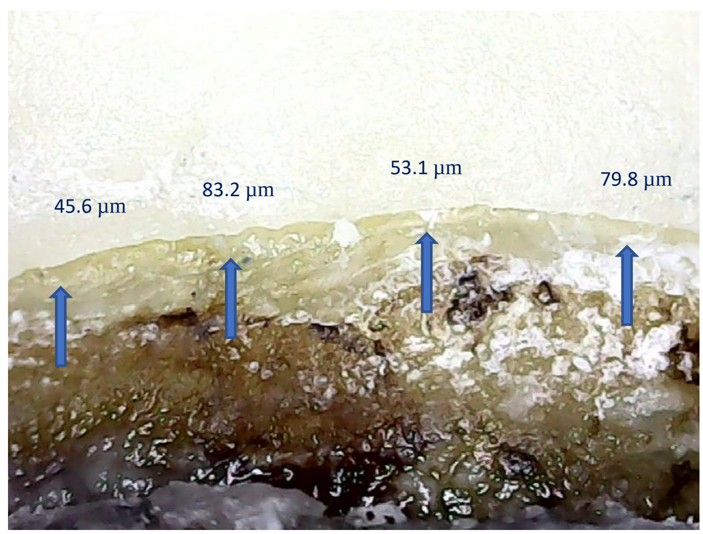


Figure (3): Showing measuring the vertical marginal gap.

Figure (4): Showing thermocycling of the samples.

Statistical analysis:

The data was presented using the mean and standard deviation values, variance homogeneity and error distribution normality were checked before running statistical tests, following that, a one-way variance analysis was performed, and if significant differences between groups were found, Tukey's post-hoc test was used. A two-way ANOVA was used to assess the effects of each factor (preparation design and thermal ageing). The study had adequate statistical power (80%) and 95% confidence level with a sample size of n=9 to find out large effect sizes for both main effects and pairwise comparisons. Graph Pad Instat (Graph Pad, Inc.) software for Windows was used to analyze the data, a statistically significant value was considered when $P < 0.05$, this rigorous statistical approach ensured a comprehensive evaluation of the obtained data.

Results:

Table (2) shows the descriptive statistics for vertical marginal gaps (µm), including mean and standard deviation (SD) values for all groups before and after thermal ageing. Figure (5) depicts a graphical representation of this data.

Before thermal aging: Among the groups studied, the ***DCh group*** (64.67± 9.712µm) exhibited the highest mean value for marginal gap, followed by the ***Ch group*** (52.40±10.16 µm). In contrast, the ***Verti group*** (41.74± 12.97 µm) displayed the lowest mean value for marginal gap, this difference was found to be **statistically significant** corresponding to the one-way ANOVA test ($p < 0.05$). The pair-wise Tukey's post-hoc test indicated a **non-significant** difference between the ***DCh group and Ch group*** at ($p > 0.05$), as shown in Table (2) and Figure (5).

After thermal aging: The investigation revealed that the ***DCh group*** exhibited the highest mean value for marginal gap (71.08±16.39µm), followed by the ***Ch group*** (61.98±7.878µm). Conversely, the ***Verti group*** displayed the lowest mean value for marginal gap (44.86±10.25µm). This difference in marginal gap means was determined to be **statistically significant**, as evidenced by the results of the one-way ANOVA test ($p < 0.05$). However, the pair-wise Tukey's post-hoc test demonstrated a **non-significant** ($p > 0.05$) difference between the ***DCh group and Ch group***, as shown in Table (2) and Figure (5).

Table (2) Descriptive statistics of marginal gap (µm) between all groups before and after thermal aging:

Variable		Thermal aging				Statistics
		Before		After		
		Mean µm	± SD	Mean µm	± SD	t-test P value
Main groups	***DCh group***	64.67^{A}	9.712	71.08^{A}	16.39	0.6443 ns
	Ch group	52.40^{A}	10.16	61.98^{A}	7.878	0.0604 ns
	Verti group	41.74^{B}	12.97	44.86^{B}	10.25	0.6261 ns
Statistics	**P value**	0.0013*		0.002*		

Significant differences between groups ($p < 0.05$) are indicated by various letters in a single column:

* (significant) ($p < 0.05$) ns: (not significant) $p > 0.05$.

The effect of thermal aging on the marginal adaptation:

Irrespective of the marginal gaps of restoration group, it was found that thermocycling **didn't significantly** affect the marginal gap mean values ($p > 0.05$) as proven by two-way ANOVA test, Table (2).

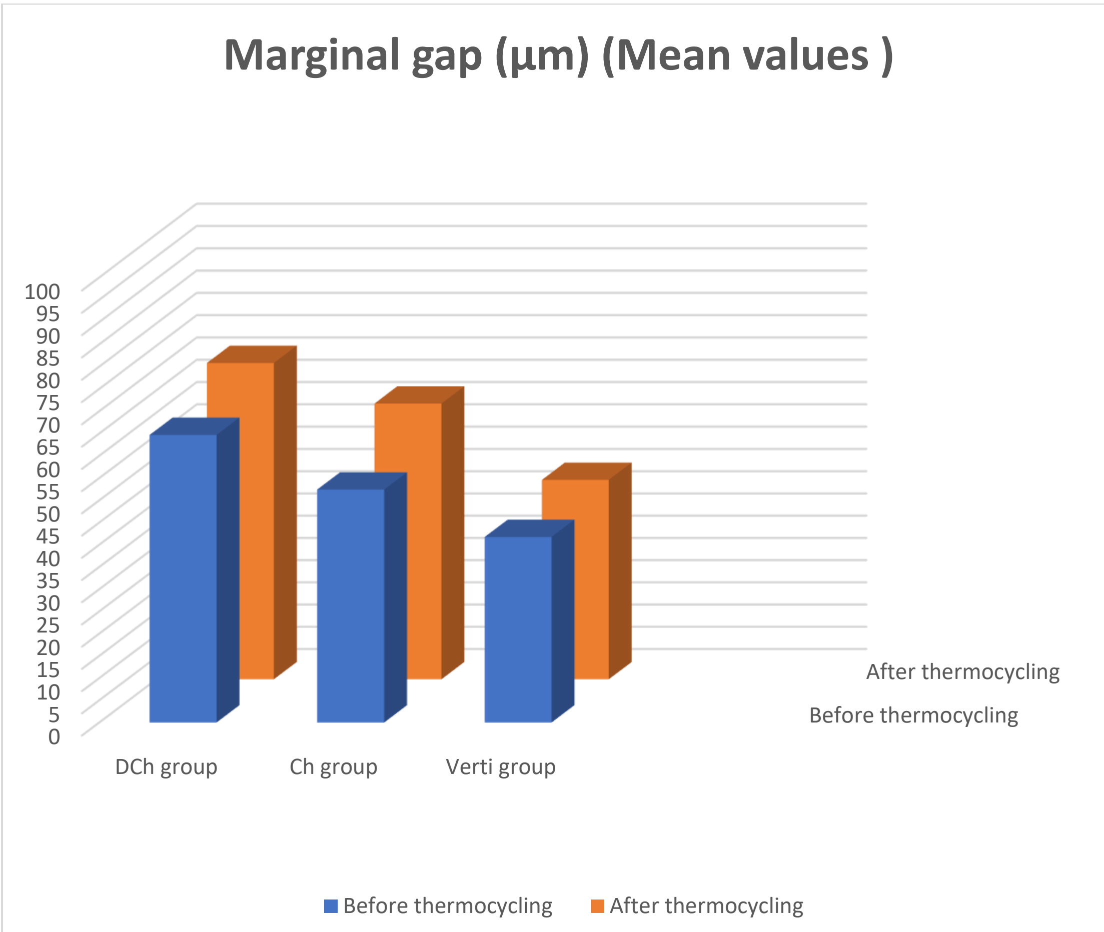


Figure (5): The tested groups' mean marginal gap values (µm) are displayed in a vertical column chart.

Discussion:

The investigation's findings led to a partial rejection of the initial null hypothesis, this was due to the one-way ANOVA test revealing a statistically significant difference between the groups under consideration; nonetheless, further examination using the pair-wise Tukey's post-hoc test revealed that there was insignificant difference among the ***DCh*** and ***Ch groups***. The second null hypothesis, on the other hand, was validated, indicating that the thermal ageing process had no significant impact on the marginal adaptability of the groups tested.

The current study found that the ***verti group*** had a significantly lower value of marginal gap (41.74, 44.86 μm) ($p<0.05$), while the ***DCh group*** had the highest value (64.67, 71.08 μm), with no significant difference between ***DCH and CH*** groups (52.40, 61.98 μm) ($p>0.05$) respectively before and after thermal ageing. Irrespective of restoration group, it was found that thermo-cycling **non-significantly** affects the marginal gap mean values. In general, the values of the marginal gap of the three tested groups in this study were found to be within the previously mentioned accepted range of marginal discrepancies.[16, 21, 31-33]

The observed significantly lower marginal gap value in the ***Verti group*** can be attributed to the restoration margin ending with an acute angle, it results in a shorter distance between the tooth and the restoration margin. This phenomenon has been elucidated by **Schillinburg et al.** [34] **and Wahsh et al.** [31]

Advanced lithium disilicate ceramic material was chosen in this study because it is a relatively innovative type of CAD/CAM material on the market that combines aesthetic and high strength benefits. Furthermore, no previous studies on the behavior of ALDs ceramic materials in terms of marginal accuracy and thermal aging have been published. As a result, the findings of this study cannot be contrasted to those of other studies.

Striking a balance between achieving optimal aesthetics and preserving the integrity of biological structures is critical in conservative dentistry. However, there is a lack of literature on the best CAD/CAM material to be used with feather-edge margins or with vertical preparations. As a result, the purpose of this in vitro study was to investigate the impact of various finish line designs on the marginal adaptation of all ceramic crowns made with advanced lithium disilicate CAD/CAM material before and after thermal ageing.

The overarching goal was to propose a minimally invasive prosthetic concept that can be used when a full coverage crown is required, with the emphasis on preserving as much natural tooth structure as possible while delivering aesthetically pleasing results.[2]

The control group in this study was comprised of a deep chamfer finish line design. Prior research has consistently advocated for the use of a deep chamfer finishing line rather than a shoulder one in all ceramic restorations, this preference can be attributed primarily to its rounded internal angles and increased thickness, both of which contribute to the improved biomechanical performance of posterior single all ceramic restorations, such characteristics have been shown to play an vital role in promoting the functionality and longevity of these dental restorations, making the deep chamfer finish line design a good clinical practice choice.[35] This study incorporated comparator groups consisting of chamfer and feather edge finish line designs, this choice was influenced by recommendations from certain authors, proposing that a chamfer finish line might be particularly suitable for small-size teeth and those with a smaller mesio-distal dimension, even though shoulder/deep chamfer finish lines may provide a superior fit. The preference for the chamfer finishing line design because of its more conservative nature and its ability to preserve the natural tooth structure with less intrusion.[33, 36] Previous studies have found that feather edge preparations have several advantages, including minimal invasiveness preparation to preserve the biological tooth structures; particularly in the cervical area, simplicity in creating impressions, and exceptional marginal adaptation and integrity.[2, 13, 35] These findings support the use of feather edge preparations as a viable alternative in specific clinical scenarios, promoting the preservation of natural tooth structures and achieving favorable treatment outcomes.

The evaluation of marginal adaptation in this study included direct visual examination combined with external measurements facilitated by a digital microscope with a 110X fixed magnification. The advantage of this technique is that it is non-invasive, which means that no invasive procedures are required. Instead, the method focuses on measuring the gap between the margins of the crown and the tooth from the outside, eliminating the possibility of errors caused by multiple internal procedures, this method not only ensures greater accuracy in the results, but it is also more cost-effective and time-efficient than other methods. As a result, in the context of this study, this non-invasive measurement method emerges as a practical and reliable means of assessing marginal adaptation.[2, 18, 30] To maintain consistency and standardization, a single operator performed all measurements in the present study.

The study's results was supported by **Fouad M**.[37] who stated that samples with a chamfer finish line had a significantly higher marginal gap than feather edge samples among her tested materials (Super transparent multilayered zirconia crowns and Zirconia reinforced lithium silicate glass-ceramic (ZLS)) at ($p<0.001$). **Almahdy et al**.[35] found that monolithic zirconia crowns with feather edge margins had a statistically significant lower marginal gap mean value than those with deep chamfer margins, which is consistent with the findings of this study. **Vasiliu et al.** [24] discovered that thermocycling and cementation had no effect on the internal and marginal fit of CAD-CAM monolithic and Heat-Pressed glass-ceramic restorations.

The outcomes of our study do not align with the findings reported by **Haggag et al.**[30], In their study, regardless of the zirconia type used, the chisel finish line group exhibited a significantly higher mean value for the marginal gap compared to the deep chamfer group. Furthermore, they stated that thermal ageing had a significant effect on the tested groups' marginal adaptation. The differences in results amongst the two studies could be attributed to variations in the luting agents and ceramic materials used in each investigation. Furthermore, **Rizonaki et al**[21] discovered that the feather-edge finish line had significantly higher marginal gap values than the other two groups (chamfer and rounded shoulder finish lines). This observation implies that the combination of CAD-CAM lithium disilicate full coverage crowns and feather edge preparation may not meet all the clinical requirements as well. Different studies' findings highlight the importance of carefully considering the materials and techniques used in dental restorations, as they can have a significant impact on the overall marginal adaptation and performance of the restorations.

One of the current study's limitations is that all marginal discrepancies were measured after cementation. It was discovered that the luting agent has an effect on the marginal gap, particularly with thermal ageing[38]; Even with this variable, all of the tested groups' marginal gaps were within the acceptable clinical range. Another limitation of this study was that only vertical marginal gaps were evaluated, whereas vertical and horizontal marginal discrepancies should be assessed separately because they have different clinical implications.

In conclusion, considering the findings and restrictions of this study, it can be reasonably concluded that, among the experienced groups, the ***Verti group*** exhibited notably superior marginal adaptation both before and after thermocycling when compared to the other groups. However, it is important to acknowledge that larger sample size studies and the implementation of standardized techniques for studying the physical and mechanical performance of advanced lithium disilicate restorations are recommended. These steps would provide more robust and comprehensive insights into the behavior and effectiveness of the tested materials, thus enhancing the overall understanding and applicability of these dental restorations in clinical practice.

Conflict of interests: There is no potential conflict of interest.

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