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Original Article

Influence of thermal aging on the marginal integrity of computer aided design/ computer aided manufacturing fabricated crowns

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Abstract *Background/purpose:* The adaptation and marginal integrity of computer-aided designed and computer-aided manufactured (CAD/CAM) crowns after exposure to thermal aging need to be investigated. The present in-vitro study was designed to investigate the marginal integrity of CAD/CAM fabricated crowns cemented on extracted teeth after thermocycling aging.
Materials and methods: Twenty-six newly extracted human premolars were prepared for full-coverage CAD/CAM crowns and were divided into two groups (leucite-reinforced glass-ceramics and lithium disilicate glass-ceramics). Both crowns' groups were cemented using dual curing resin cement. All specimen margins were measured for marginal integrity using an imaging system 24 h post cementation; then after 1, 3, and 5 estimated clinical years (10,000, 30,000, and 50,000 thermocycles). Two-way ANOVA analysis were used to determine whether the mean value difference is significantly different ($\alpha = 0.05$).
Results: The average margin gaps recorded for leucite-reinforced glass-ceramic crowns were: 82.61 μm initial, and 91.02 μm after 5 estimated clinical year). For the lithium disilicate glass-ceramic crowns, the average margin gaps recorded were: 100.01 μm initial, and 120.21 μm after 5 estimated clinical year. During all measuring intervals, the leucite-reinforced glass-ceramic crown group had a lower marginal discrepancy. No statistically significant difference between the two groups was recorded.
Conclusion: After being subjected to thermocycling, both CAD/CAM ceramic crowns, exhibited an increase in their marginal discrepancy; the difference was within the accepted clinical range.

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Introduction

The evolutions of digital dentistry reached the stage of the construction of an extra coronal restoration in one patient visit. The digital dentistry evolution occurs through computer-aided design/manufacturing (CAD/CAM) systems (CAD/CAM) systems in dentistry use machinable ceramic blocks to construct all-ceramic restorations.[1] With the evolution of CAD/CAM technology, there has been a rapid increase in the use of glass-ceramics.[2] The increase in preference and demand for esthetic restorations by patients and clinicians has led to increased interest in developing new materials that are esthetically superior. In this regard, glass-ceramics are frequently the material of choice due to their biocompatibility and exceptional esthetics, and they are withstanding to masticatory forces.[2] Recently, there has been an increased demand and acceptance of all ceramic restorations by both patients and clinicians, and this is due to the advancement in materials and the reported longevity. All ceramic restorations, including ceramic CAD/CAM crowns, have evolved to become standard practice for the general dentist.[3]

High-strength glass or silicate ceramics had been considered one of the best translucent materials that can also, tolerate oral environmental conditions. Leucite-reinforced ceramics and lithium disilicate ceramics are an example of silicate ceramics that are indicated for single posterior crowns.[4] Leucite-reinforced glass-ceramics are manufactured under the trade name IPS Empress CAD blocks (IPS Empress CAD blocks, Ivoclar, Vivadent, Schaan, Liechtenstein) using a one-stage crystallization process. Leucite crystals addition to the ceramic, helped to reduce generation and propagation of crack, improves the strength and fracture toughness. Leucite-reinforced glass-ceramics has good semitransparency with a low flexural strength (185 MPa) with a high Weibull modulus of 16.10.[5,6] While, lithium disilicate are a glass matrix and lithium disilicate crystals with a high flexural strength (530 MPa), high Weibull modulus (13.4), and a 0.20% linear shrinkage.[5,6] Lithium disilicate has excellent mechanical properties and fracture toughness, with a high esthetical appearance and good bonding to tooth structure.[7] Internal and marginal adaptations are crucial, and key for long-term survival for any extra coronal restoration, especially for CAD/CAM fabricated restorations. Marginal discrepancies can be classified into horizontal, vertical and compete misfit.[8] The space between the prepared tooth and the crown margin known as the marginal gap. In the case of CAD/CAM ceramic crowns, the marginal gap can be estimated using several methods, including visual inspection, tactile probing, and digital imaging; overall, digital imaging is considered the most accurate and reliable method for estimating the marginal gap for CAD/CAM ceramic crowns.[9]

Marginal misfit or discrepancies in any extra coronal restoration might clinically result in a defect between the tooth and the crown which leads to the accumulation of plaque around that area. An inadequately fit might have a negative effect on long-term survival or durability of the restoration.[10] More minor marginal discrepancies were found in interim CAD/CAM crowns compared to PMMA crowns.[11]

It is always essential to examine the performance of dental materials in an environment that mimick the thermal changes in the oral environment. The most common procedure for thermal or artificial aging is thermocycling which is a technique that simulates the natural aging process of dental materials by exposing them to the recurrent temperature range of 5–55 °C exposures of dental materials in the oral environment Thermocycling, on the other hand, involves subjecting the material to repeated cycles of temperature change, which simulates the effects of thermal stress on the material in the mouth. It has been reported that 10,000 cycles are equivalent to an estimated one year in clinical service.[12]

There was a variation in the clinically acceptable marginal gap, the typical clinically acceptable marginal gaps for conventional crowns were reported to be 120 to 150 μ m, and for multiple system CAD-CAM crowns the acceptable values encompass between 50 and 200μ m.[8,13] The clinically acceptable marginal gap criterion has been confirmed in other studies.[14,15] The variation of the clinically acceptable marginal gaps was due to the variable study protocol and evaluation methods. There are various techniques for the assessment of the marginal gap of indirect restorations.[8,16,17]

The present investigation aimed to examine and compare the marginal integrity of CAD/CAM crowns made of leucite-reinforced glass and lithium disilicate glass-ceramics fabricated on extracted teeth after thermal aging, using a 3D profilometer.

Materials and methods

Specimen preparation

The calculated sample size was 14 teeth, Using the following formula and type I/II error rate was set to a = 0.5 with 80% power. The sample size was increased to 26 to account for any failure/loss/fracture of the sample during the experiments. Twenty-six caries-free extracted human premolars maxillary (13 samples) and mandibular (13 samples) with relatively similar dimensions (mesiodistally and buccolingually) were chosen for the present investigation. Prior to the preparation, the sample teeth were disinfected for one week using a 0.5% chlorine solution; an ultrasonic scaler was used to remove the soft tissues and calculus deposits. Then the samples were kept at room temperature in distilled water prior to testing procedures. Each sample tooth was embedded at an upright position in vinyl polysiloxane (VPS, Kerr Extrude XP, kerr Corp. Romulus, MI, USA) material with 2 mm exposed from the cementoenamel junction (CEJ), as shown in Fig. 1. VPS was chosen due to

Figure 1 Tooth VPS model for the standardization of the preparation.

the flexibility of removing the teeth from the platform if needed.

Crown preparation

The teeth were prepared following the manufacturer's recommendation of at least a 1.0 mm shoulder margin with internal rounded angles, 1.5 mm occlusal reduction, and 1.5 axial reductions (Fig. 1). A new bur for the Planmeca milling machine was used for every preparation. The cervical margins were placed 1 mm above the cementoenamel junction using 4.5× magnification. Impressions were made prior to preparing the teeth using VPS material. These impressions were used as reduction guides to verify a standardized preparation and design the CAD/CAM crown anatomy.

Fabrication of the crowns

In the first group, thirteen ceramic crowns were fabricated using leucite-reinforced glass-ceramics (IPS Empress CAD blocks, Ivoclar, Vivadent). The second group uses lithium disilicate glass-ceramics (IPS e. max CAD blocks Ivoclar, Vivadent, Schaan, Liechtenstein). Thirteen ceramic crowns were fabricated. Fig. 2 shows the digital workflow which was applied to all samples. An imaging powder was applied to the preparations with an aerosol to obtain good contrast. Each specimen was scanned using the Emerald TM intraoral scanning system (Planmeca, D4D Tech. 650 International Pkwy Richardson, TX, USA).

The CAD/CAM Compare software (Planmeca) was utilized to trace the cervical margin. The Compare software offers the crown's design using the program's default settings, as shown in Fig. 2. The design was then sent to the milling unit to be processed. The crowns were fabricated using a PlanMill 40S milling machine (Planmeca). After milling, the crown's internal, proximal, and occlusal fit were assessed. The lithium disilicate group specimens were then placed in the furnace in their metasilicate blue state for crystallization (Programat P500, Ivoclar Vivadent, Schaan, Liechtenstein) combined with glazing (Crystall/Glaze, Ivoclar Vivadent, Schaan, Liechtenstein) to convey the final crystallization and shade of the lithium disilicate crowns. Following the manufacturer's recommendations, the leucite-reinforced group specimens were placed in the glazing furnace (Crystall/Glaze, Ivoclar Vivadent). All samples were processed using the same milling unit, and replaced the burs after each restoration to limit any variation.

Cementation procedure

Before cementation, all-ceramic crowns' marginal fit was checked using a 5.0× magnifying lens. No adjustments were performed for any sample. If the crown fit was not acceptable, the sample was discarded and milled a new restoration. All sample teeth were stored in distilled water prior to cementation. A 9.6% hydrofluoric acid gel (Lot no. 181130, Pulpdent, Watertown, MA, USA) was applied to etch the restoration inner surface for 60 s, a water spray was used to rinse the etch. Following the drying of the crowns using oil-free air; a thin silane coat (Monobond Plus; Ivoclar Vivadent, Schaan, Liechtenstein) was smeared for 60 s and finally the crowns were dried with oil-free air. A pumice in a rubber cup was used to clean the surface of the prepared teeth. After a thoroughly rinsing of the prepared teeth a dual-curing resin cement (Rely-X Unicem, 3M-ESPE, Saint Paul, MN, USA) was used according

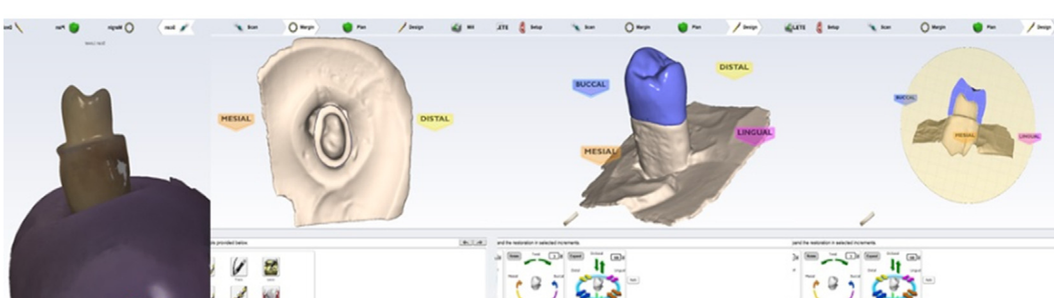

Figure 2 Scanning and digital processing of the crowns.

to the manufacturer's instructions and placed on the inner surface of the restoration. The crowns were seated on their corresponding tooth using slight pressure (finger pressure) as at clinical cementation, after which gently removed of excess cement was conducted. Post-cementation, all the restored teeth were stored in artificial saliva (Lot no. 007042, Pickering Laboratories, Mountain View, CA, USA) at room temperature for 24 h prior to taking measurements.

Marginal gap evaluation

All specimen margins were measured 24 h post-cementation before being subjected to thermocycling. The thermocycler water baths were set to 5 °C and 55 °C for 20 s at each temperature. Readings were taken at 10,000 thermocycles (1 estimated clinical year), 30,000 thermocycles (3 estimated clinical years), and 50,000 thermocycles (5 estimated clinical years).[12] The marginal gap of all restorations in each group ($n = 26$) was recorded using a digital microscope (VR-3100; Keyence, Japan) at six preselected locations (mesial buccal, straight buccal, distal buccal, distal lingual, straight lingual, and mesial lingual) at 40× magnification. The gap width was evaluated and recorded as the vertical distance between the tooth structure and restoration interface at a constant predetermined location per tooth.

Statistical analysis

One examiner took all measurements, and an intra-examiner reliability percentage was calculated using the Kappa test (89%). All data were summarized and tabulated for further analysis. Descriptive analysis was carried out by computing the mean and standard deviation for continuous variables using a statistical software program (IBM SPSS Statistics, v23; IBM Corp). After verifying equal variance, a two-way ANOVA analysis was used to determine whether the mean value difference was significantly different ($\alpha = 0.05$).

Results

The mean value was recorded at every four intervals. The average margin gaps recorded for the leucite-reinforced glass-ceramic crowns were initially 82.61 ± 27.13 μm, 83.12 ± 20.01 μm after 1 estimated clinical year, 86.23 ± 27.12 μm after three estimated clinical years, and 91.02 ± 21.11 μm after 5 estimated clinical years.

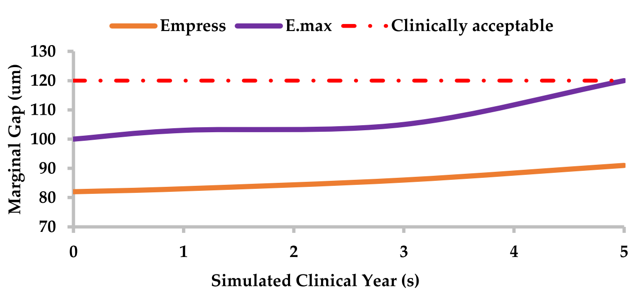

Figure 3 Average marginal gap for the examined crowns up to five simulated clinical years.

For the lithium disilicate glass-ceramic crowns, the average margin gaps recorded were, initially, 100.01 ± 26.74 μm, 103.92 ± 21.80 μm after one estimated clinical year, 105.04 ± 23.52 μm after 3 estimated clinical year, 120.21 ± 23.04 μm after 5 estimated clinical years shown in Fig. 3. During all measuring intervals, the leucite-reinforced glass-ceramic group had a lower marginal discrepancy than the lithium disilicate group. Although the total margin discrepancy after 50,000 cycles (5 estimated clinical years) was 120 μm for the lithium disilicate group and 91 μm for the leucite-reinforced group, the two-way ANOVA analysis showed no statistically significant difference between the two groups of CAD/CAM ceramic crowns (Table 1). Photographically, the loss of bonding resin between the restoration and tooth interface is most noticeable on the edges, as seen in Figs. 4 and 5. However, it is important to note that loss of resin was present around the circumference of the restoration.

Discussion

The marginal gap is an essential indicator of the long-term success of any restoration, and the investigation of this factor was the main purpose of this study. In general, glass-ceramic materials possess several advantages that make them one of the best choice for permanent fixed restoration and are widely used for the replacement of single crowns; glass-ceramics possess the strengths and the esthetics.[18] Nowadays, several CAD/CAM materials and production techniques are available. The glass-ceramic materials in this study have different crystalline compositions that require a different fabrication technique. Inherent fabrication errors include operator variables, intrinsic limitations of the milling unit, and software design algorithms. Operator variables include clinical skill limitations and digital workflow expertise.[19] Accuracy and consistency are important factors for the success of CAD/CAM ceramic restorations.[20] To limit these variables, all specimens were processed entirely by one individual. All samples were processed using the same milling unit, and replaced the burs after each restoration to limit this variable.

There is a significant deficiency of consensus in relation to the method of investigating marginal adaptation of crowns and bridges.[21] Digital imaging is considered the most accurate and reliable method, but other methods can still be helpful as adjuncts or when digital imaging is unavailable. It was reported that the non-contact scanning method used in the present investigation was considered the best in vitro evaluation method for evaluating marginal discrepancy.[22] A recent investigation evaluating the marginal and internal fit of different zirconia crowns by comparing direct and indirect digitalization concluded that direct digitization showed smaller gaps in axial and marginal regions than indirect digitalization.[23]

Cement thickness plays an important role and can directly affect the marginal adaptation of CAD/CAM crowns; a decreased cement space may increase the marginal discrepancy.[24] To minimize these errors, the fit was checked prior to cementation. In addition, to minimize the

Table 1 Comparison of the marginal gaps for the examined groups.

Material	Number of samples	Aging	Mean ± standard deviation	95% CI
E.max	**13**	Initial	100.01 ± 26.74	[87,113]
		After 1 clinical rear	103.92 ± 21.80	[84,122]
		After 3 clinical years	105.04 ± 23.52	[91,119]
		After 5 clinical years	120.21 ± 23.04	[108,132]
Empress	**13**	Initial	82.61 ± 27.13	[74,90]
		After 1 clinical year	83.12 ± 20.01	[73,93]
		After 3 clinical years	86.23 ± 27.12	[77,95]
		After 5 clinical years	91.02 ± 21.11	[84,98]
Comparison between groups/time interval		[a]**t (149, 0.05)**	***P-value*** **(α = 0.05)**	
E.max vs **Empress** (initial)		1.99	0.069(Not significant)	
E.max vs **Empress** (1 Clinical year)		1.98	0.071(Not significant)	
E.max vs **Empress** (3 Clinical years)		1.98	0.071(Not significant)	
E.max vs **Empress** (5 Clinical years)		1.98	0.071(Not significant)	

[a] Two-way ANOVA analysis.

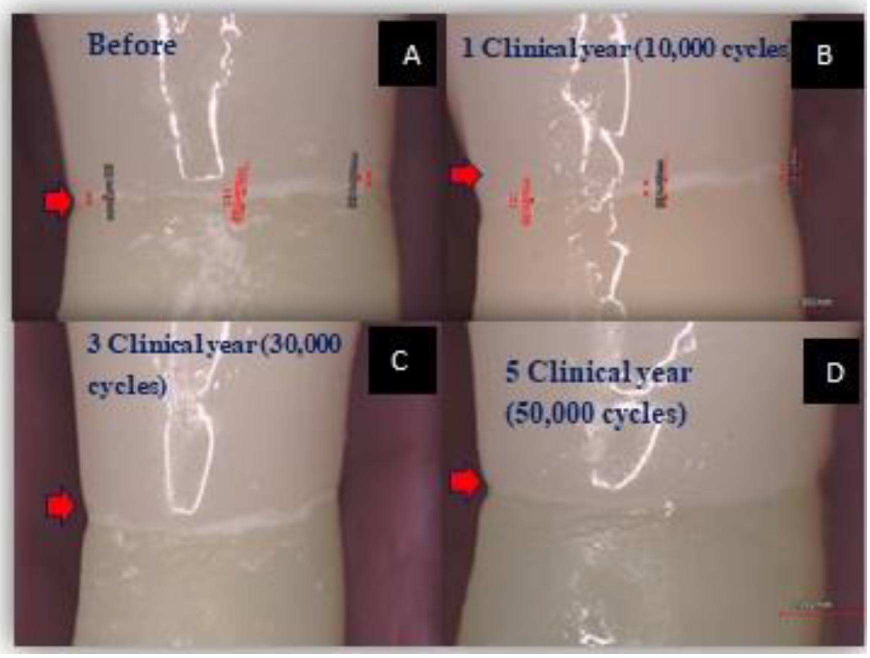

Figure 4 Leucite reinforced sample at initial (A); 10,000 cycles (B); 30,000 cycles (C); and 50,000 cycles (D).

variability, no modifications were made. If the crown fit was not acceptable, restoration was discarded and a new restoration was milled again.

Some studies suggest that a marginal gap of 50–120 μm is optimal for the long-term success and longevity of the restoration; marginal gaps more significant than 120 μm may increase the risk of cement washout and microleakage, while gaps less than 50 μm may increase the risk of marginal fracture or chipping.[8,13] The current findings come into agreement with a recent investigation that evaluated the marginal fit of lithium disilicate crowns with different finish lines.[25] While the leucite-reinforced group marginal gap was lower than that of the lithium disilicate group, the two examined groups exhibit marginal gaps within the clinically acceptable gap (120 μm). The present findings come into agreement with previously reported results that confirmed the presence of an increase in the marginal gap that lithium disilicate CAD/CAM crowns.[26,27] Previously, it was suggested that the marginal gap of lithium disilicate crowns is significantly improved by crystallization firing. It was also indicated that frequently changing milling burs for lithium disilicate crowns helps provide crowns with a more accurate marginal fit.[27] Earlier, it was indicated that a marginal gap of more than 120 μm would accelerate the deterioration of luting cement, leading to microleakage.[28] On the other hand, some researchers reported that the limit of marginal discrepancy for CAD/CAM restoration should not exceed 100 μm.[29,30] Other studies reported that the average

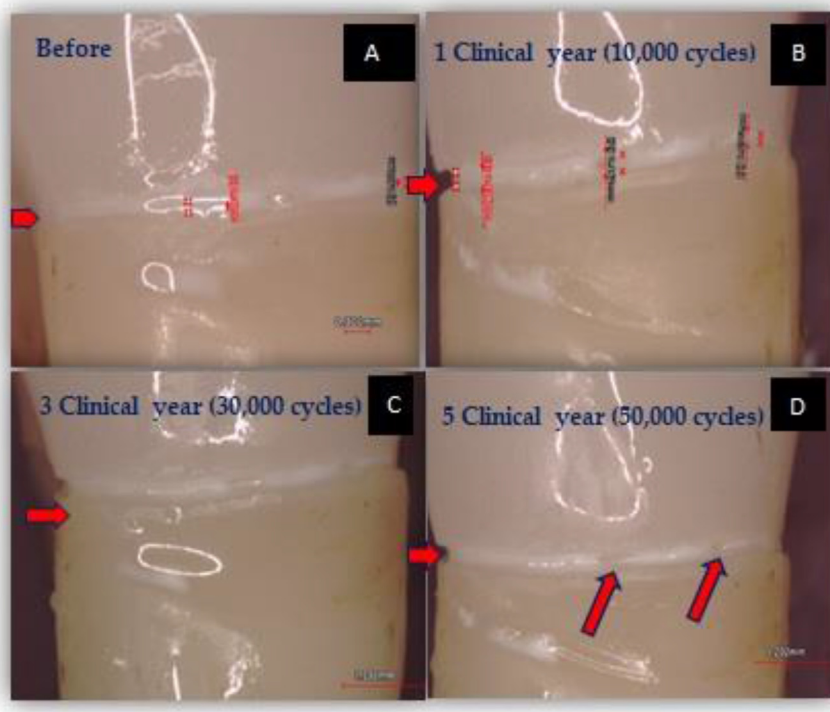

Figure 5 Lithium disilicate sample at initial (A); 10,000 cycles (B); 30,000 cycles (C); and 50,000 cycles (D).

marginal gap leucite-reinforced group was from 23 to 92 μm, which comes into agreement with the present findings.[14,31] The teeth used in the present investigation were all premolar to get similar buccolingual and mesiodistal dimensions simultaneously; this could be considered a limitation of this study. Having 26 premolars with almost the same dimension limited the current investigation sample size. It is important to remember that estimating the marginal gap for CAD/CAM ceramic crowns is an essential aspect of the restorative process that can impact the long-term success and longevity of the restoration. Future research on CAD/CAM technology for dental restorations should explore the use of more diverse tooth types and systems beyond just molars to evaluate the effectiveness and reliability of the technology for various clinical scenarios. In conclusion, thermal aging showed that both investigated CAD/CAM ceramic crowns have developed marginal discrepancies within the accepted clinical range (120 μm).

Declaration of competing interest

The authors declare no conflicts of interest with respective to the research and publication of this article.

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