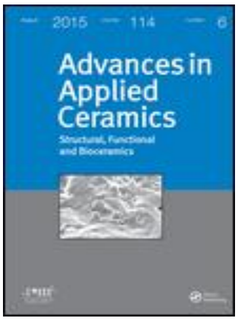

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Marginal adaptation of different hybrid ceramic inlays after thermal cycling

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ABSTRACT
The aim of the study was to evaluate the marginal adaptation of various hybrid ceramics inlays before and after thermal cycling. Twenty-four extracted human molars were received inlay preparation, and randomly divided into three groups ($n = 8$/group). Specimens were restored with Ceramage by experienced technician, Enamic or Lava Ultimate by CAD/CAM using CEREC Omnicam. After cementation, all restorations were subjected to thermal cycling. Marginal gaps were measured under a stereomicroscope. The overall mean marginal gaps of the three groups were significantly different ($p < 0.05$) before thermal cycling, which were all within the clinically acceptable range. The digital intraoral impression and CAD/CAM systems did not show superior accuracy compared to the traditional technique, during the hybrid ceramic inlays manufactured operation. Thermal cycling had no effect on marginal adaptation of the different hybrid ceramic inlays ($p > 0.05$). Gingival margin presented larger gaps compared to occlusal and axial margin in all hybrid ceramic inlays.

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Hybrid ceramic material; inlay restoration; marginal adaption; thermal cycling

Introduction

Inlay is a kind of dental restoration made outside of a tooth to correspond to the form of the prepared cavity, which is then luted into the tooth [1]. Inlay technique is introduced to rehabilitate decayed posterior teeth in addition to overcome some of the problems associated with direct filling techniques such as inadequate proximal or occlusal morphology, insufficient wear resistance, or mechanical properties of directly placed filling materials [2]. In the dental field, inlay restorations are widely used. The traditional technique of making inlays requires taking impressions and the restorations are manufactured on the plaster models in laboratory. With the development of materials and equipment, digital systems such as computer-aided design and computer-aided manufacturing (CAD/CAM) have evolved as an alternative for traditional technique. An intraoral scanner is used to perform the 'impression' of the preparation, then the restoration is designed and milled by a CAD-CAM system [3].

In the meantime, different materials are available for inlays, while ceramics are traditionally preferred. Ceramic restorations are characterised by their ability to restore the natural tooth morphology and achieving acceptable aesthetic results with highly survival rates. The 5-year survival rate for ceramic inlays is exceeding 90% [4–7]. However, the Young moduli of ceramics is much higher than that of dentin, so they cannot withstand elastic deformation [8]. Therefore, ceramic fractures are the most common technical complication [5,7]. Currently, hybrid ceramics have been introduced, they are manufactured by polymer-infiltrated ceramic network or polymeric matrix reinforced by ceramic fillers [9–16]. They combine the polymer and ceramic, which result in greater strength and better load distribution. Consequently, cracks and fractures of restorations are reduced [8]. Compared with traditional ceramics, hybrid ceramics are characterised by having a greater modulus of resilience [16]. Additionally, their Young moduli are close to that of dental tissue [9,16]. Because of excellent aesthetics and easier reparability, hybrid ceramics have been widely used for the fabrication of inlays [17–20].

Marginal adaptation is important for inlay restorations to avoid resin cement wear and plaque accumulation. Poor marginal adaptation correlates with increased exposure of the luting material to the oral environment and encouraged microleakage, leading to secondary caries and endodontic complications [21,22]. Moreover, the longevity of the restoration is compromised [23]. The alternating contraction and expansion of the material when subjected to change in temperature is another key factor for the microleakage [24]. It has been confirmed that the dissimilar coefficient of thermal expansion between tooth structure and the restorative material, resulted in the occurrence of microleakage [24]. This kind of thermal stresses naturally occurred *in vivo*. Thus, thermal cycling has been widely accepted as a method to represent these phenomena *in vitro* [25].

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Considering the evidence that microleakage of restoratives is influenced by their marginal adaptation and thermal properties, the aim of this *in vitro* study was to evaluate the marginal adaptation of various hybrid ceramics inlays before and after thermal cycling, and assessed whether they were clinically acceptable.

Materials and methods

Twenty-four intact molars were collected after extracted because of severe chronic periodontitis. A standardised mesio-occlusal-distal inlay cavity preparation was done in these teeth. The occlusal cavity width was 3 mm, while depth was 2 mm. Pulpal floors were prepared flat, and angles were rounded. The walls of the occlusal and proximal boxes were 6° divergence. Mesial and distal finishing lines of the proximal boxes were 1 mm under the cementoenamel junction (Figure 1).

The prepared teeth were embedded in epoxy resin with silicone rubber gums, forming #14–17 artificial dentitions (#16 was the preparation), which divided into three groups ($n = 8$) randomly. These prepared teeth then be restored by three kinds of inlay restorations:

Group CE: Teeth restored with Ceramage (Shofu, Kyoto, Japan) by experienced technician.

Group EN: Teeth restored with Enamic (Vita Zahnfabrik, Bad Säckingen, Germany) using CEREC Omnicam.

Group LU: Teeth restored with Lava Ultimate (3M ESPE, St Paul, MN, USA) using CEREC Omnicam.

The manufacturer information and technical profiles of the restorative materials were shown in Table 1.

Fabrication and adhesion of restorations

In group CE, conventional impressions of vinyl polysiloxane impression material (Aquasil Ultra and Aquasil Soft Putty, Densply, York, PA, USA) were taken under the manufacturer's instruction using individual trays

Figure 1. Occlusal view of the standardised mesio-occlusal-distal preparation.

Table 1. Technical profile and manufacturer of the materials evaluated.

	Ceramage	Vita Enamic	Lava Ultimate
Abbreviation	CE	EN	LU
Type	Light-curing micro hybrid composite	Polymer-infiltrated ceramic network (PINC)	Composite resin nanoceramic
Matrix	Organic polymer matrix	UDMA TEGDMA	Bis-GMA UDMA Bis-EMA TEGDMA
Filler	Zirconium silicate micro ceramicmicro-fine ceramic (progressive fine structured filler)	Feldspar ceramic enriched with aluminium oxide	Silica (20 nm) zirconia(4–11 nm) zirconia-silica clusters (0.6–10 μm)
Filler% by weight	73%	86%	80%
Manufacturer (country)	Shofu Kyoto, Japan	Vita Zahnfabrik Bad Säckingen, Germany	3M/ESPE St Paul, MN, USA

Note: UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-GMA, bisphenol A glycidyl methacrylate; Bis-EMA, bisphenol A polyethylene glycol diether dimethacrylate.

[26]. The stone casts were made with type IV gypsum (Heraeus, Hanau, Germany) 24-h later.

The stone dies were prepared in the stone casts. Then, two layers of die spacer were applied (about 30 μm thickness per layer, Ceramage spacer, Shofu, Kyoto, Japan), 1 mm away from the margin area. Inlays were made in Ceramage on the die by an experienced technician. The restorations were polymerised with a laboratory curing unit (Solidilite V, Shofu, Kyoto, Japan) following the manufacturer's recommendations.

In EN and LU groups, Omnicam intraoral scanners (Sirona Dental System, GmbH, Bensheim, Germany) were used to get the digital impressions, after the artificial dentitions fixed in the dental simulator. CEREC 4.2 was used to design the inlays. The simulated cement thickness was set at 60 μm, 1 mm away from the margin. The final inlays were machined with the milling machine (CEREC MC XL).

All cementation procedures followed the manufacturer's recommendations. The teeth were etched with 37% phosphoric acid for 30 s in enamel and 15 s in dentin. The inlays were cemented into the teeth by dual-polymerising resin composite Variolink N (Ivoclar Vivadent, Schaan, Lichtenstein). The restorations were loaded under 1 kg of force to ensure fully seated when cemented. The restorations were light-cured for 40 s at each surface. Then any excess cement was removed.

Thermal cycling procedures

The specimens were subjected to thermal cycling in water baths between 5°C and 55°C, after stored in distilled water at 37°C for 24 h. The dwell time was 30 s at each temperature, and the transfer time was 5 s.

The marginal gaps were measured at 0, 1000, 5000, and 10,000 cycles, respectively.

Marginal gap evaluation

Marginal gaps were measured under a stereomicroscope (Leica MZ 16A, Leica Microsystems, Switzerland) by one operator, observed eight locations of each inlays, two on the gingival (one mesial and one distal) and four on the axial (one mesial-buccal, one distal-buccal, one mesial-lingual and one distal-lingual) and two on the occlusal surface (one occlusal-buccal and one occlusal-lingual) of the MOD inlay (Figures 2 and 3).

Statistical analysis was performed by one-way ANOVA in combined with LSD post hoc test ($p = 0.05$). Software SPSS 20.0 was used.

Results and discussion

Marginal adaptation of inlays made from different hybrid ceramic materials and fabrication technique was significantly different

The overall mean marginal gaps (μm) of the three groups before thermal cycling were significantly different ($p < 0.05$): CE = 80. 89 (±26.49), LU = 91.19 (±29.77), EN = 100.49 (±32.03) (Table 2).

The quality of the marginal adaptation is one of the factors that affected the longevity of an indirect restoration. The clinically acceptable marginal gap values for dental restorations are different among studies and range from 20 to 150 μm [27–29]. However, a gap lower than 120 μm is suitable, which suggested by many authors [30–34]. The overall mean marginal gaps of inlay restorations of the hybrid ceramic inlays of the present study were 80–100 μm after cementation. These values were all within the clinically acceptable range.

The direct measurement technique was used to measure the marginal gap for the inlays in the present study, which has been used in several studies [35–38]. This technique is less time-consuming than other indirect methods and reduces the errors that may emerge from specimen preparation [39].

Many factors influence marginal adaptation of CAD/CAM inlay restorations, including restorative materials [29,40–46], luting space value [29,43,46], cementation [40,47], thermomechanical loading [44,45,47–50] and so on. Hence all these factors should be considered when different studies are compared. For example, Sener-Yamaner et al. [40] evaluated the marginal gap of CAD/CAM-fabricated Lava Ultimate inlays after cementation, and the results were lower (84.78 μm) than the present study. In contrast, Bottino et al. [29] evaluated the marginal gap of CAD/CAM-fabricated enamic inlays before cementation, and the results were higher (163.1 μm in axial and 159.6 μm in occlusal) than the present study. The variation in luting space value setting is the possible explanation. The luting space value setting in the software of Sener-Yamaner's study was 30 μm, the value of Bottino's study was set to 80 μm. Based on these previous studies, the luting space was set to 60 μm in present study.

Traditional technique of making inlays needs a conventional impression with elastomeric materials to produce a gypsum cast. This methodology leads to several potential sources of error because of dimensional deformations along the process chain [51]. However, in the present study, the digital intraoral impression and CAD/CAM systems did not show superior accuracy when compared to the traditional technique. This result agreed with Addi's [52] and Rippe's [43] studies, reported that there were only slight differences of fit between the restorations fabricated using different manufacturing techniques. The possible reason is that the complex geometry of an inlay restoration influences the accuracy of the intraoral scan [53–55]. Moreover, the preparation influences the quality of the image captured. In present study, the occlusal depth was prepared to 2 mm from the occlusal margin, and the convergence

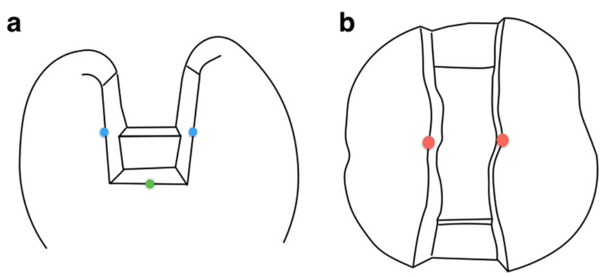

Figure 2. Location of the points where the marginal gaps were measured. (a) Location of measuring points mesially and distally: blue point – axial locations; green point – gingival locations; (b) location of measuring points on the occlusal aspect: red point – occlusal locations.

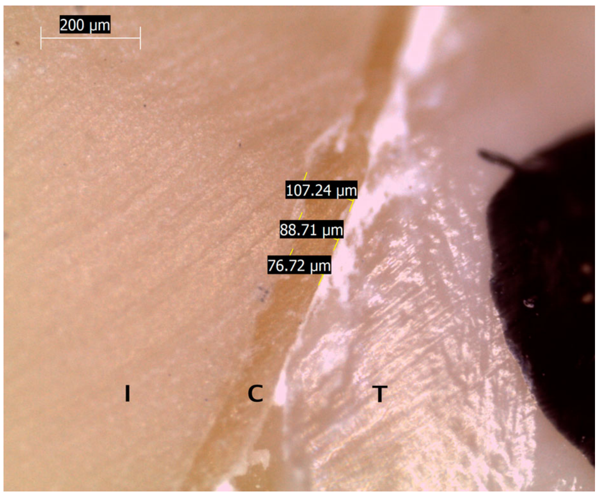

Figure 3. Representative image of an inlay under optical microscopy (T: tooth, C: cement, I: inlay).

Table 2. Results of the mean marginal gap and standard deviation (SD) of the materials evaluated at each surface and overall mean marginal gap and SD of each material before thermal cycling.

Groups ($n = 8$)	Inlay surface	Mean marginal gap (μm)	Standard deviation (SD)	Overall mean marginal gap (μm)	Standard deviation (SD)
CE	Gingival	98.48[a]	23.44	80.89[a]	26.49
	Axial	78.3	23.17		
	Occlusal	72.21	29.65		
EN	Gingival	111.58[a]	31.4	100.49[a]	32.03
	Axial	100.73	31.47		
	Occlusal	90.26	32.1		
LU	Gingival	102.43	27.35	91.19[a]	29.77
	Axial	86.48	29.41		
	Occlusal	94.74	30.26		

Note: Values with the same superscript letter are not significantly different ($p < 0.05$).
[a]Different superscript letters in same column indicate significant difference ($p < 0.05$).

of the preparation was six degrees, following the clinical practice. However, larger convergence angle is benefit to optical capture and enhance the accuracy of intraoral impression. According to the research of Hoop et al., the inlay preparation for CAD/CAM should present 1.5–2 mm of pulpal floor depth, and the box walls should diverge in an occlusal direction by more than 10 degrees, to make optical capture easier and reduced the risk of excessive binding during seating [56]. The paradox is that excessive convergence angle results in reducing the retention force of the inlay restoration.

Thermal cycling had no effect on marginal adaptation of different hybrid ceramic materials

Thermal cycling simulates the temperature changes in the oral cavity, and shows the dissimilar coefficient of thermal expansion between tooth and restorative material [57,58]. The bath temperature and dwell time in present study were chosen based on previous research [59]. It has been reported that most studies used bath temperatures of 5°C and 55°C, and dwell times of 30 s. ISO recommends 500 thermal cycles [60]. However, many studies suggest that 500 times should be the lowest number of thermal cycles [61,62]. Stewardson et al. [62] demonstrated that 500 thermal cycles can only simulate hot and cold changes in the oral cavity for 2 months. Gale et al. [61] indicated that thermal cycling needed 10,000 times to simulate the temperature change in the mouth for one year. Therefore, in present study, up to 10,000 cycles were used.

After 10000 thermal cycles, the overall mean marginal gaps (μm) for the 3 groups were: CE = 84.54 (±28.96), LU = 94.99 (±32.78), EN = 105.79 (±34.20). Thermal cycling had no effect on overall mean marginal gaps ($p > 0.05$). The trend of overall mean marginal gap of each group after different numbers of thermal cycles was depicted in Figure 4. The results had no significant difference ($p > 0.05$).

The thermal properties are influenced by the nature and structure of the material. The findings of present study suggest that hybrid ceramic materials may have similar linear coefficients of thermal expansion with tooth structure. The one-year duration of thermal

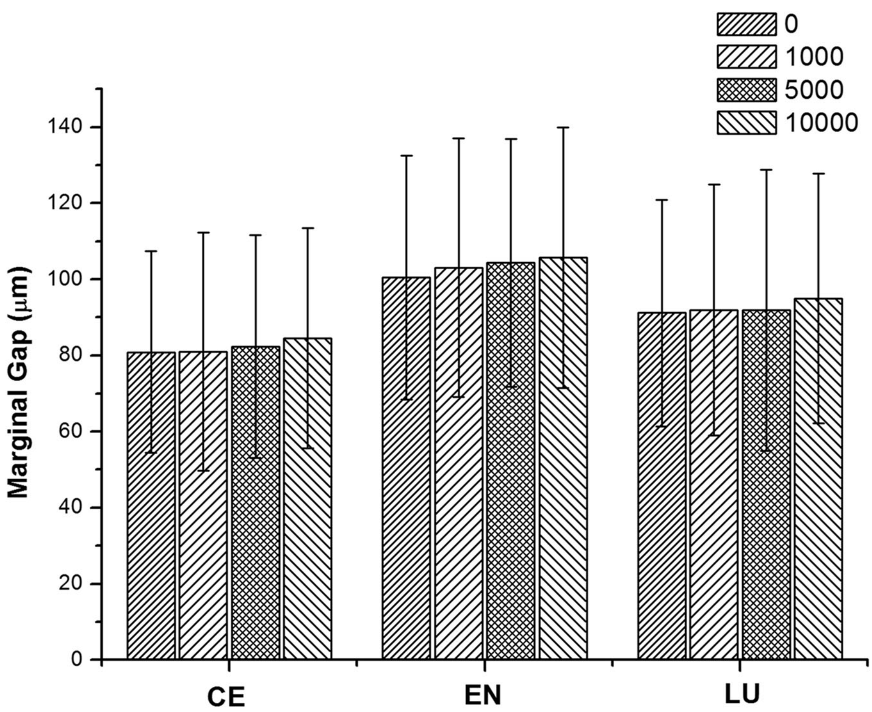

Figure 4. The trend of overall mean marginal gap of each group.

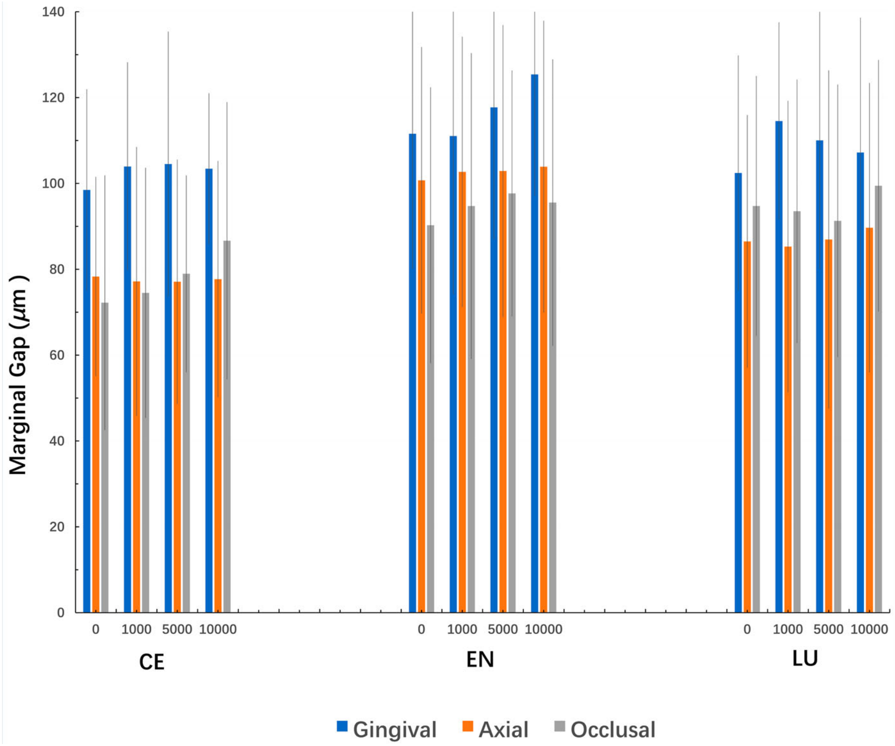

Figure 5. The trend of different surfaces' marginal gaps of each group before and after different thermal cycles.

changes usually occurring in the mouth will not have a great impact on the hybrid ceramic material's dimensional alteration and thus will not affect marginal integrity.

Marginal adaptation of different surfaces of inlays was significantly different

Figure 5 summarised the marginal gap measurements per surface in the three groups. The mean marginal gaps of different surfaces were various in all groups. Overall, gingival mean marginal gap calculations were higher than that of other surfaces (axial and occlusal) in all groups ($p < 0.05$). No significant differences were found between the occlusal and axial marginal gaps. The larger gap in gingival margin is due to the deform and polymerised shrinkage of the impression material in the CE group, related to the manufacture operation. While the higher gap value in gingival margins of CAD/CAM inlays (EN and LU groups) are affected by many factors. When getting the digital impressions, the dentitions from groups EN and LU were fixed in the dental simulator simulating the oral conditions. The scanning head must be adjusted into several directions to overcome the adjacent teeth blocking and get the intact image of gingival margin. It was reported that when obvious angles (>60°) exist between the perpendicular of scanned surface and the scanning direction, the accuracy of digitisation declined [63]. Another possible reason could be the milling units and the lack of precision of the drills shaping the gingival area [64]. Over milling of any surface details less than the diameter of the milling rotary instrument will result in a less accurate restoration [55,65]. In addition, software limitations in designing restorations and hardware limitations within scanning equipment and the milling machine are possible shortcomings in the CAD/CAM technique [47].

Conclusion

Within the limitations of this in vitro study, it was concluded that:

(1) Thermal cycling had no effect on marginal adaptation of the hybrid ceramic inlays.
(2) The gingival margin of the hybrid ceramic inlays presented larger gaps compared to occlusal and the axial margin.
(3) The overall mean marginal gaps of inlay restorations made by the hybrid ceramic were all within the clinically acceptable range.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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