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Marginal Gap, Internal Fit, and Fracture Load of Leucite-Reinforced Ceramic Inlays Fabricated by CEREC inLab and Hot-Pressed Techniques

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Abstract

Purpose: This in vitro study was designed to evaluate and compare the marginal gap, internal fit, and fracture load of resin-bonded, leucite-reinforced glass ceramic mesio-occlusal-distal (MOD) inlays fabricated by computer-aided design/manufacturing (CAD/CAM) or hot pressing.

Materials and Methods: Fifty caries-free extracted human molars were prepared for standardized MOD inlays. Impressions of each specimen were made and poured using type IV dental stone. Dies were randomly divided into two equal groups. Twenty-five ceramic inlays were fabricated by the hot-pressed technique using IPS Empress leucite-reinforced glass ceramics, and the other 25 ceramic inlays were produced by CAD/CAM technology using ProCAD leucite-reinforced ceramic blocks and CEREC inLab facilities. Inlays were bonded to the teeth using a dual-cured resin cement. The specimens were stored in distilled water at 37°C for 24 hours and then thermocycled for 5000 cycles. The marginal gap measurements were taken with a stereomicroscope. Specimens in each group of inlay systems were randomly divided into two subgroups of 10 and 15 specimens each. Ten specimens in each subgroup were sectioned mesiodistally for evaluation of the internal fit. The fracture load of specimens in the second subgroup (n = 15) of the two inlay systems was determined under compressive load in a universal testing machine. Data were analyzed using Student's t-test at a significance level of $p < 0.05$.

Results: The mean marginal and internal gap size in both IPS Empress and ProCAD inlays were less than 100 μm; however, the marginal gap for the IPS Empress restorations was significantly higher than that of ProCAD restorations ($p < 0.05$). There was no significant difference in the mean internal fit or the fracture load between the two glass ceramic inlays ($p > 0.05$).

Conclusions: The leucite-reinforced glass ceramic inlay restorations fabricated by CEREC inLab (CAD/CAM) and the hot-pressed technique provided clinically acceptable marginal and internal fit with comparable fracture loads after luting.

Growing interest in tooth-colored nonmetallic posterior restorations has stimulated interest in the development of new materials and methods in esthetic dentistry. For such applications, dental ceramics are often the material of choice because of superior esthetics, biocompatibility, and resistance to masticatory forces.[1] Many types of ceramic materials and fabrication methods are available for the construction of esthetic all-ceramic restorations. One of these dental applications is the computer-aided design/manufacturing (CAD/CAM) system. The CEREC system uses CAD/CAM technology developed in the 1980s. The hardware and software of this system has been extensively revised and improved.[2] Today CEREC 3 for clinical use and CEREC inLab for laboratory use are available.[3] The ceramic restorations are milled from machinable ceramic blocks made from ceramic powder fused at high temperature to ensure a reliable and homogenous structure.[4]

One of the alternative techniques for making all-ceramic restorations in the laboratory is high-temperature injection molding (hot pressed). IPS Empress is a leucite-reinforced glass ceramic manufactured with this technique and designed for restoring single units, including veneers, inlays, onlays, and crowns.

Marginal and internal adaptations are crucial, especially for ceramic inlay restorations, to minimize subsequent marginal ditching or wear of the luting resin. The presence of marginal discrepancies in the restoration exposes the luting resin to the oral environment. This may lead to a loss of bonding or an incomplete bonding of the restorative material/bonding agent, bonding agent/cement, cement/dentin bonding agent, or dentin bonding agent/tooth interfaces. The resultant microleakage permits the percolation of food, oral debris, and other substances that can act as potential irritants to the vital pulp.[5-7] Furthermore, a poorly fitting restoration is not well supported by the tooth substance, perhaps influencing the longevity of the restorations.[8]

Another important aspect of the restored tooth is its resistance to fracture from masticatory forces. The structural integrity of the restored tooth is more important than the strength of the materials used. The fracture strength of a restored tooth is increased significantly when the restoration is bonded to the tooth tissue.[9] With the use of materials that can be adhesively bonded to the tooth, the application of more minimal preparation designs has also been possible. Minimally prepared resin-bonded CEREC inlays did not compromise the initial structural integrity of teeth restored either with resin composite or ceramic inlays.[10]

Several studies have examined the marginal adaptation of different ceramic inlay systems and have shown acceptable results.[11-14] However, the marginal and internal fit of leucite-reinforced glass ceramic mesio-occlusal-distal (MOD) inlays made by the hot-pressing technique do not appear to have been compared to those made by the CEREC inLab CAD/CAM machine. Thus, the purpose of this study was to evaluate and compare the marginal and internal fit and also the fracture load of leucite-reinforced glass ceramic MOD inlay restorations fabricated by these two fabrication techniques after luting.

Materials and methods

Specimen preparation

Fifty caries-free human maxillary and mandibular extracted molars with similar buccolingual and mesiodistal dimensions were selected for this study. The teeth were disinfected with a 0.5% chloramine solution for 1 week. Periodontal ligaments, calculus deposits, and soft tissues were cleaned using an ultrasonic scaler. The teeth were stored in distilled water at room temperature until testing procedures were initiated. The root of each tooth was embedded in a cold-curing acrylic resin up to 2 mm from the cementoenamel junction. Standardized MOD cavities with flat pulpal floor and rounded angles were prepared with a straight fissure flat-ended diamond bur (Diatech Dental, Coltene-Whaledent, Altstätten, Switzerland) on a high-speed handpiece with water spray cooling. A new bur was used for every five preparations. The width of the occlusal cavity was set at 1/3 of that of the tooth, and the occlusal depth was prepared to 3 mm from the occlusal margin. The cervical margins of proximal boxes were 1 mm above the cementoenamel. The width of the proximal box was 1/3 of the buccolingual distance at the level of the gingival floor. The occluso-gingival dimension of the proximal box was approximately 3.0 to 3.5 mm, depending on the length of the crown. Occlusal divergence of buccal and lingual walls in the proximal boxes was approximately 6°, measured using a surveyor and adjusted by one operator. Hollow ground finish lines with no bevel were prepared in all cavosurfaces (0.5 mm deep) with round diamond burs except gingival cavosurfaces. Impressions were made of the prepared teeth with the condensation-cured silicone impression material (Speedex; putty and light body wash, Coltene Whaledent USA, Mahwah, NJ) from the prepared teeth. All models were poured using type IV dental stone (Elite Rock stone, thixotropic, Lot 8641, Zhermack SPA, Rovigo, Italy). The stone dies of maxillary and mandibular molars were randomly divided into two groups.

In the first group, as control, 25 ceramic inlays using IPS Empress leucite-reinforced glass ceramic ingots (Lot F65031, Ivoclar Vivadent, Schaan, Liechtenstein) were fabricated by the hot-pressing technique according to the manufacturer's instructions. Die spacer was applied to the stone dies, and wax patterns were fabricated according to appropriate anatomic functional form of each tooth. The inlay wax patterns were invested (Empress Refractory Investment, Ivoclar Vivadent), and the IPS Empress ingots were heated and pressed into the investment mold after the burn-out of the wax analog. The investment was divested from the specimens by sandblasting with 50 μm alumina particles at an air pressure of 0.5 MPa. The ceramic inlays were cleansed by placing them in Invex liquid (Ivoclar Vivadent) for 20 minutes and rinsed with water for 2 minutes.

In the second group, 25 ceramic inlays were fabricated by CAD/CAM technology using ProCAD leucite-reinforced glass ceramic blocks (Lot F67171, Ivoclar Vivadent) and CEREC inLab facilities (Sirona Dental System, GmbH, Bensheim, Germany). An imaging powder (Sirona imaging powder: Vita CEREC powder, Sirona Dental System) was applied into the preparations with an aerosol to obtain a good contrast. Each die of the CAD/CAM inlay was mounted in the laser-scanning holder of the milling chamber, where the laser scanner automatically traces the preparation and transmits the data to the computer. As soon as the die had been scanned, the data were assembled into a graphic depiction of the inlay preparation. The computer graphic design program was then used to trace the cavosurface margins. The software proposed the design of inlay based on the recorded data and the default setting of the program. The program processed the information from the completed inlay design, the prefabricated ProCAD ceramic block was inserted into the milling chamber, and the inlay was milled.

Cementation procedure

Marginal and internal fit of all inlays were checked with a magnifier prior to cementation. Minimal adjustment of the internal surfaces of the inlays was performed. The adjustments were

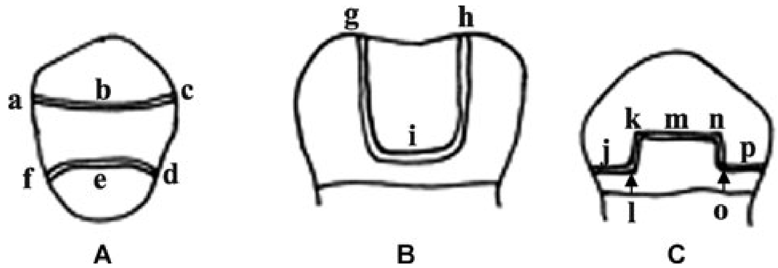

Figure 1 (A) Location of measuring points on the occlusal aspect; (B) Location of measuring points mesially and distally; (C) Mesiodistal section showing location of the internal measuring points.

performed using a blunt diamond bur after it was shown by a silicone indicator paste (Fit Checker, GC, Tokyo, Japan). All restorations were then cleaned ultrasonically in distilled water for 15 minutes. The inner surfaces of the restorations were then etched with a 9% hydrofluoric acid gel (Ultradent Products, Inc., South Jordan, UT) for 1 minute, rinsed with a water spray, and dried with oil-free air. Two layers of a silane solution (Monobond S, Ivoclar Vivadent) were applied to the bonding surfaces of ceramic inlays and allowed to air dry for 60 seconds. A bonding agent (Heliobond, Ivoclar Vivadent) was then applied and light cured for 10 seconds with a halogen-curing light (Coltolux II, Coltene Whaledent USA) at an intensity of 600 mW/cm^2.

The prepared surfaces of the teeth were cleaned with pumice in a rubber cup and rinsed thoroughly. Enamel margins of the prepared teeth were etched with a 35% phosphoric acid etchant (Ultra-Etch, Ultradent Products, Inc.) for 20 seconds and the dentin surfaces were etched for 10 seconds. Subsequently, the teeth were rinsed with water and gently air dried to remove excess water, leaving the cavity visibly wet. Then a dual-cured bonding agent (Excite DSC, Ivoclar Vivadent) was applied to the etched surfaces of teeth and light cured for 20 seconds. A dual-cured resin cement (Variolink II, Lot L03630, Ivoclar Vivadent) was used according to the manufacturer's instructions and placed on the inner surfaces of all restorations and cavity walls. The inlays were then seated on their corresponding teeth at room temperature with finger pressure as at clinical cementation, and the excess cement was gently removed. Polymerization of the luting agent was performed by light curing the restoration from the occlusal, buccal, lingual, and proximal surfaces for 20 seconds in each aspect. Finishing and polishing were completed with superfine diamond burs under water cooling. All the restored teeth were stored in distilled water at 37°C for 24 hours and then subjected to thermocycling at 5000 cycles in water baths between 5°C and 55°C, 1 minute at each temperature.

Marginal gap evaluation

Subsequently, the teeth were coated with nail varnish, ending 2 mm below the restoration margins. To make the resin cement in the marginal gap between the tooth substance and the inlay clearly visible, the resin cement was stained by immersing specimens in aqueous solution of 0.2% basic fuchsin dye at room temperature for 24 hours. The marginal gap of all inlay restorations in each group (n = 25) was measured with a stereomicroscope (SZX 12, Olympus, Tokyo, Japan) at 12 preselected locations (occlusal, mesial, and distal margins) at 40× magnification (Fig 1). The gap width was measured as the shortest distance between the enamel cavosurface margins and the inlays at the measuring points as described previously.[8]

Internal fit evaluation

Twenty-five specimens in each group were randomly divided into two subgroups for internal fit (n = 10) and fracture resistance (n = 15) evaluations. For internal fit measurement, 10 specimens in the first subgroup of each ceramic inlay system (CEREC inLab and hot pressed) were embedded in clear acrylic resin and sectioned mesiodistally using a diamond wheel. The internal gap distance between the inlay and the tooth substance was then measured with the stereomicroscope at seven preselected locations at 40× magnification (Fig 1). To avoid interpretation errors resulting from the presence of excess cement, all external measurements were recorded 50 μm from the outermost margin. All measurements were carried out by the same operator.

Fracture load measurement

The load to fracture for 15 specimens in the second subgroup of each inlay system was determined. A stainless steel ball with a 5 mm diameter mounted in a universal testing machine (Z020, Zwick/Roell, Ulm, Germany) was used to apply compressive loads along the long axis of the restored teeth at a 0.5 mm/min crosshead speed until fracture. A thin plastic tape was placed on the surface of the ball to ensure a stable contact between the steel ball and tooth structure. The steel ball contacted the buccal and lingual triangular ridges beyond the margins of the preparations/restorations. The compressive load (N) required for causing fracture was recorded for each specimen.

The data obtained for the marginal gap, internal fit, and fracture load were analyzed statistically using the Student's t-test to determine significant differences between the two ceramic inlay systems. The selected level of statistical significance was $p < 0.05$.

Results

The results of the marginal gap, internal fit, and fracture load measurements for the two ceramic inlay systems evaluated are shown in Table 1. The mean marginal gap for the IPS Empress restorations was significantly ($p < 0.05$) higher than that of the ProCAD inlays; however, there was no statistically significant difference ($p > 0.05$) between the average internal fit for the IPS

Table 1 The mean marginal gap, internal fit, and fracture load data for groups tested (standard deviation in parentheses)

Ceramic inlays	Marginal gap (μm)	Internal fit (μm)	Fracture load (N)
IPS Empress	56 (18)	17 (5)	1505 (956)
ProCAD	36 (11)	23 (9)	1050 (763)

Empress and ProCAD restorations. No significant difference was found in the mean fracture load values for the IPS Empress and ProCAD inlay restorations ($p > 0.05$).

The types of fracture observed for each type of ceramic inlays are listed in Table 2. The predominant type of fracture involved the lingual or the buccal cusp with part of the restoration for both inlay systems. Few fractures were through the ceramic restoration vertically. Only one specimen in each group fractured at the bonding interface between the restoration and tooth.

Discussion

Various types of ceramic systems for fabricating inlay restorations in posterior teeth are becoming increasingly popular. Ceramic inlays are usually cemented with an adhesive technique by resin-based composite cements. Since the high fracture resistance and satisfying marginal conditions achieved after cementation are the most relevant for long-term clinical performance of fixed restorations, evaluation of these variables was the main purpose of this study.

The two glass ceramic systems used in this study have the same crystalline composition but were produced with two different fabrication techniques. ProCAD is a leucite-reinforced glass ceramic similar to IPS Empress, but with a finer particle size.[15] There are some fabrication errors inherent with these fabrication techniques. Three main factors may affect the accuracy of fit of the CEREC method. Operator variables, such as clinical skills and expertise with the CEREC machine, are the first factor. Second, the intrinsic limitations of devices such as the milling unit, and finally, the software program and the design algorithms employed will determine the accuracy of the proposed restoration design.[5] The lost-wax technique is used for the fabrication of IPS Empress restorations. Thermal shrinkage of wax pattern and the ceramic coping occurs upon cooling at room temperature and casting, respectively. This thermal shrinkage is compensated by the setting and thermal expansion of the phosphate-bonded investment. Thus, the net dimension of a cast IPS Empress ceramic coping is the result of the contraction and expansion of different materials used in its fabrication.[7]

Table 2 Types of fracture observed for the bonded inlay restorations

Ceramic inlays	Tooth and part of restoration	Through the restoration	Tooth/restoration bonding interface
IPS Empress	11	3	1
ProCAD	13	1	1

It should be noted that there are some problems in measuring the distance between tooth substance and ceramic inlays after luting the restorations with a resin cement. Determining the dividing line between inlay/luting agent and luting agent/tooth even through a dark shade of cement is difficult.[8] Staining the resin cement with fuschin in this study made the joint clearly visible; however, a very thin excess of cement or enamel bonding agent in some areas covered the inlay or enamel surfaces. Although the restorations had been finished with superfine diamonds, the excess resin in some areas made it difficult to detect the dividing line. Furthermore, there were some positioning errors in placing the ceramic inlays in the cavities filled with the resin cement as compared with the position obtained in the empty cavities; however, the overall fit of the ceramic restorations before cementation was checked in the same manner as in a clinical procedure in the present study. These are small practical errors to be considered.

The results of this study showed an average marginal gap of 56 ± 18 μm and 36 ± 11 μm for the IPS Empress and ProCAD inlays, respectively. Although the marginal gap for the ProCAD restorations was significantly lower than that of the IPS Empress restorations ($p < 0.05$), the two glass ceramic systems produced marginal gaps less than 100 μm that were well within the maximum clinically acceptable gap.[16] It has been reported that a marginal gap of more than 100 μm would accelerate the deterioration of the luting cement, and a 100 μm gap is considered as the maximum acceptable gap in clinical situations.[17]

In addition, no statistically significant difference between the average internal fit for the IPS Empress (17 ± 5 μm) and ProCAD restorations (23 ± 9 μm) was observed ($p > 0.05$). The two inlay systems in the present study were fabricated with two different techniques by two different operators. Thus, it would be reasonable to assume that there must have been differences in the initial fit of the inlays before luting; however, no significant difference in the internal fit for the two inlay systems was found after luting. This may be due to the properties of the resin cement used (medium viscosity), which influenced the final internal gap distances when the inlays were luted.[8]

Comparison of the values of marginal gap width and internal fit of the ceramic inlays reported in other studies might be confusing. Many variables such as type of tooth preparation, location and number of measuring points, measuring technique, the type of resin cement and the method used for fabricating the ceramic inlays will influence the obtained results.[18,19] These should be considered when the data are compared.

An average marginal gap from 23 to 92 μm for the IPS Empress system has been reported by other studies,[7,20,21] and appears to be consistent with the findings in this study. Sjögren evaluated the marginal and internal fit of IPS Empress inlays using the In-Ceram, Celay, and CEREC 1 systems.[8] Although he considered the fit satisfactory, the overall gap measured was higher than 100 μm for all-ceramic inlay restorations. A better adaptation for CEREC 2 has been shown when compared to the values reported for CEREC 1.[22]

The results of the present study are consistent with the findings of previous studies that demonstrated a clinically acceptable gap width of less than 100 μm for the hot-pressed and CAD/CAM all-ceramic restorations.[16,23,24] Similarly, the marginal and internal gap dimensions of the CEREC inLab crown copings have been reported to be in accordance with the dimensions of the conventional hot-pressed method.[25]

The fracture load of the two glass ceramic MOD inlay restorations was also compared in this study. Teeth in posterior regions are subject to functional and para-functional forces with varying magnitudes and directions.[26] Several factors affect the in vitro fracture load of all-ceramic restorations, such as microstructure of the ceramic material, the fabrication technique, the ceramic surface finish, and the luting method. Other important factors are the storage conditions, shape of metal rod, and the direction and location of load application.[27-29]

In this study, a round-end metal rod similar to dental cusps was chosen to be in contact with the cusps of the tooth rather than restorative material because tooth fracture load depended on only the remaining tooth structure, not the restorative material.[30,31] In addition, forces generated intraorally during function vary in magnitude, application, speed, and direction, whereas forces applied in vitro are at a constant direction and speed, and continually increase until fracture occurs.[30] Thus, the loading and environmental conditions during testing might not correspond to the oral condition; however, the purpose behind fracture strength is not primarily to simulate the clinical condition, but to determine if the structural integrity of the restored tooth is in any way affected by the choice of manufacturing route for the inlay restorations. If one or other process compromised the structural integrity (i.e., the strength of the restored tooth), that would suggest this could result in a reduction in long-term durability.

A higher fracture load for the IPS Empress inlay restorations than the ProCAD inlays was recorded, although the mean values were not significantly different ($p > 0.05$). Also, no apparent difference in the type of fracture was observed between the two ceramic inlay systems. Large variability in fracture load of the inlays was observed, consistent with other studies for fracture strength tests.[32,33] This is consistent with a brittle fracture system with a dispersion of flaws of different sizes and despite standard procedures of collecting, storing, and preparing the teeth and the conditions of milling the inlays, it is impossible to control the size and distribution of internal flaws of each tooth structure or milling block.[34]

Increased leucite dispersion of the IPS Empress glass ceramic caused by the pressing process can improve its mechanical strength. Modification to the manufactured Empress ingot or the spruing or pressing procedure may also help to produce more uniform leucite dispersion, reducing the susceptibility of the glassy matrix to fracture.[35] On the other hand, machining systems can create a multitude of flaws of a sufficient size to act as fracture sources. These flaws may be related to both material and machining variables, which dramatically improve fracture possibilities.[36] In contrast, Stappert et al reported a significantly higher fracture load for CAD/CAM-produced ProCAD partial coverage restorations than that of leucite or lithia disilicate glass ceramics (IPS Empress and IPS e.max press) fabricated by hot pressing.[37] In another investigation, no significant difference in the fracture load of IPS Empress 2 (hot pressed) and ProCAD (CEREC 3, CAD/CAM) all-ceramic crowns and the luting agent was found, neither was this affected by cyclic loading.[27] Empress 2 is a lithium disilicate glass ceramic and has a higher fracture strength than ProCAD, but this is not reflected in the fracture strengths of the restored teeth. Also, clinical trials have shown the treatment option to restore posterior teeth with pressed glass ceramics and CAD/CAM fabricated restorations to be reliable.[38,39] All of this indicates that the strength of the ceramic may be less of a critical factor in determining the fracture strength of the restored tooth.

There are some limitations to this study. First, the large standard deviations observed in the present study could be due to small sample size and limitations in producing identical specimens because of inevitable practical errors. Second, the results reported will not reflect the actual values in clinical situations because of different environmental and loading conditions.

Conclusions

The two leucite-reinforced glass ceramic inlays fabricated by hot-pressed or CEREC inLab (CAD/CAM) technique provided a clinically acceptable marginal and internal fit after luting. There was no statistically significant difference in fracture strength for the IPS Empress and ProCAD inlay restored teeth.

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