Marginal and internal fit of four different types of ceramic inlays after luting

An in vitro study

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Sjögren G. Marginal and internal fit of four different types of ceramic inlays after luting. An in vitro study. Acta Odontol Scand 1995;53:24–28. Oslo. ISSN 0001-6357.

The marginal and internal fit of four different types of ceramic inlays—Cerec, Celay, Empress, and Vita In-Ceram Spinell—was determined after they had been luted on extracted premolars. For the Cerec inlays sharp and U-shaped proximal box shapings were also compared. There was no statistically significant difference either in the proximal fit or in the gingivoproximal fit between the four inlay systems studied, with the exception of the Cerec inlays made for preparations with sharp proximal boxes, which had wider marginal gaps. At the occlusal margins a significant-principle order of the gap width was established. The best internal fit was recorded for the Celay inlays, whereas there was no significant difference in the internal fit between the other systems. For the Cerec inlays the U-shaped proximal box shaping improved the marginal accuracy all around the restoration. □ *CAD-CAM; cementation; composite resin cements; dental ceramics; dental porcelain*

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The fit of ceramic inlays is a matter of current interest, highlighted since the introduction of CAD/CAM-manufactured restorations. The values for the marginal gap between restoration and tooth substance reported for ceramic inlays have in some studies been close to those reported for cast gold inlays (1–4). In most studies, however, larger gap values than for cast gold inlays have been reported, both for CAD/CAM-manufactured and for other types of ceramic inlays (5–7).

The thickness of the layer of composite resin cements used for luting of ceramic inlays seems to influence clinically important properties of the resin cement. For example, Feilzer et al. (8) have shown that the wall-to-wall contraction of the composite resin cement increases with decreasing wall-to-wall distance. Moreover, after thermocycling and mechanical loading a lower degree of dye penetration was found to occur at interproximal margins of ceramic inlays with wide luting spaces as compared with inlays with small luting spaces (9), and in a study by Dietschi et al. (10) it was shown that the cement thickness did not influence the marginal or internal seal of ceramic inlays luted with composite resin cements. However, the conventional opinion is that well-adapted inlays are desirable, since the composite resin cement is considered to be the weakest part of the restoration, and wide marginal gaps may result in increased wear of the luting cement (11) and washouts predisposing for failure of the restorations. Leinfelder et al. (12) have, from a theoretical point of view, suggested as a general rule that the interfacial gap should not exceed 100 μm, particularly on the occlusal surfaces, since wider gaps commonly may result in extensive wear of the composite resin luting agents. Furthermore, the internal adaptation of ceramic inlays is of importance, since poorly fitting inlays are supported mainly by the luting cement rather than the tooth substance, which might influence the longevity of the restorations. However, little information is currently available with regard to the internal adaptation of luted ceramic inlays.

The aim of the present study therefore was to determine in vitro the marginal and internal fit after luting of ceramic inlays manufactured with four different techniques.

Materials and methods

Fifty mesio-occluso-distal cavities were prepared in 50 sound, caries-free, extracted human premolars that had been stored in 0.5% benzalconium chloride solution. Ten of them were prepared for Cerec restorations (Cerec System, software C.O.S. 2.0, Siemens AG, Bensheim, Germany) with sharp proximal boxes as recommended by Mörmann & Brandestini (13), and 10 for Cerec restorations prepared with U-shaped proximal boxes. The other 30 teeth were prepared for ceramic inlays on the basis of the concept of standard class-II preparations with flat bottom and all angles rounded. All of the 50 preparations had cervical shoulders, and no cavosurface bevels were made. The walls of the preparations were prepared to meet the tooth surface at or near a right angle. Preparation depth was about 2.0 mm, and the buccolingual width of each inlay preparation was half that of the intercuspal dimension. All the cavity margins were located in enamel.

For the 20 cavities designed for Cerec, the ceramic inlays were manufactured by means of the CAD/CAM technique. Both the videocamera and the milling machine of the Cerec equipment used were first calibrated. The ceramic blocks used were Vita Cerec Mark II (Vita Zahnfabrik, Bad Säckingen, Germany). To make the surfaces of the teeth opaque and nonreflecting before the optical impression, Dentaco scan white (Dentaco Dentalindustrie und -marketing GmbH, Bad Homburg, Germany) was used.

Once preparations were completed for the other 30 premolars, the teeth were randomly divided into three groups of 10, for which 10 Empress (Ivoclar AG, Schaan, Lichtenstein), 10 Vita In-Ceram Spinell (Vita Zahnfabrik), or 10 Celay (Mikrona Technologie AG, Spreitenbach, Switzerland) inlays were manufactured. The ceramic blocks used for the Celay inlays were Vita Celay Blanks (Vita Zahnfabrik). All of these 30 inlays were manufactured indirectly by means of diestone models (Kerr Vel-Mix Stone ISO Type IV, Kerr Europe AG, Basel, Switzerland) after impressions with an A-silicon (President, Coltène, Altstätten, Switzerland). The Vita In-Ceram Spinell and Empress inlays were produced by specialized dental technicians at two licensed dental laboratories, one for each technique. The Cerec inlays were manufactured by the author, and the Celay inlays by a specially trained dental technician at The Department of Dental Materials Science, Umeå University. All tooth preparations, impression-takings, and cementation procedures were performed by the author. Before the inlays were luted, their fit was checked on the extracted premolars in the same manner as in a clinical standard procedure—that is, the restorations had to be acceptable for permanent placing in patients.

In accordance with the manufacturers' instructions all the internal surfaces of the inlays, with the exception of the Vita In-Ceram Spinell inlays, were etched with 4.9% HF acid. The Vita In-Ceram Spinell inlays were not etched. Instead, their internal surfaces were blasted with aluminum oxide with a size of 25 μm in accordance with the manufacturer's instructions. After silanization of the 50 inlays they were all luted with a dual-cured hybrid composite resin cement (Kerr Porcelite Dual Cure, Kerr AG, Basel, Switzerland; batch 7513 35 for the base and 7509 94 for the catalyst). Before cementation the enamel margins of the prepared teeth were etched with a 36% phosphoric acid gel. Subsequently, the teeth were rinsed with water and dried with compressed air. The enamel bonding agent used was recommended by the manufacturer (Kerr Bondelite Resin and Kerr Bondelite Activator; batch 3604–18501 for the resin and 18500 for the activator), and the inlays were seated on the extracted premolars at room temperature with finger pressure as at clinical cementation. Polymerization of the dual-cured resin composite cement was achieved by means of a halogen lamp (Norlite, Germany) directed for 60 sec at each restored surface. After polymerization, excesses of cement were removed with superfine diamonds and/or Sof-Lex polishing disks (3 M Dental Products Division, St Paul, Minn., USA).

To make the composite resin cement in the marginal gap between the tooth substance and the inlay clearly visible, the resin cement was stained by placing the restored teeth in a solution of 4% erythrosine (LIC Dental, Solna, Sweden) and 95 vol% ethyl alcohol in white spirit for 4 days. The marginal gap was thereafter measured with a Leitz UWM-DigS measuring microscope at 20 preselected locations at 10× magnification (Fig. 1a–b). The precision of the measuring microscope used was 0.5 μm—that is, the shortest distance that could be determined with the microscope was 0.5 μm. The gap width was measured as the shortest distance between the enamel cavosurface margin and the inlay at the measuring points. After this the teeth with the luted inlays were ground from the lingual surface down to the mesiodistal center of each inlay, using a diamond wheel. The internal gap distance between the inlay and the tooth substance was then measured with the measuring microscope at seven preselected locations at 10× magnification (Fig. 1c). The measurements were carried out by the same person, and all measured values were rounded off to the nearest 5 μm.

Statistical analysis

The values obtained were analyzed statistically using the unpaired Student's t test.

Results

The mean values, standard deviations, and ranges of the marginal and internal gaps of the different ceramic inlay systems are shown in Table 1.

The CAD/CAM-manufactured inlays (Cerec) made for preparations with sharp proximal boxes had wider mean gaps ($p < 0.01$) at the proximal margins than the other inlays, between which there was no statistically significant difference ($p > 0.05$). At the gingivoproximal locations the Cerec inlays made for preparations with sharp proximal boxes had wider mean marginal gaps ($p < 0.001$) than the Celay inlays, the Vita In-Ceram Spinell inlays, and the Cerec inlays made for preparations with U-shaped proximal boxes, but there was no statistically significant difference in the gingivoproximal fit between the three latter inlay systems ($p > 0.05$). Between the Empress inlays and all the other inlays there was no statistically significant difference with regard to the gingivoproximal fit ($p > 0.05$).

At the occlusal margins statistically significant differences were observed between the four inlay systems.

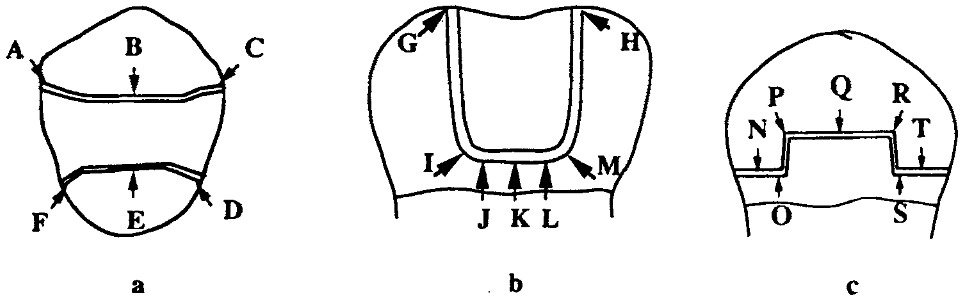

Fig. 1a. Location of the occlusal measuring points. 1b. Location of the mesial and distal measuring points. 1c. Mesiodistal section showing location of the internal measuring points.

The Empress inlays showed a better occlusal fit than all the other inlays ($p < 0.001$). The Vita In-Ceram Spinell inlays had a better occlusal fit than the Celay inlays ($p < 0.001$), and the Celay inlays a better occlusal fit than the Cerec inlays made for U-shaped proximal boxes ($p < 0.05$). The Cerec inlays made for U-shaped proximal boxes showed a statistically significant better occlusal fit than the Cerec inlays made for sharp proximal boxes ($p < 0.001$).

With regard to the internal fit a significantly better fit ($p < 0.01$) was observed for the Celay inlays than for the three other types of inlay, whereas no significant differences were observed between the Empress, the Vita In-Ceram, and the Cerec inlays ($p > 0.05$).

Discussion

Various types of ceramic inlays in posterior teeth are becoming increasingly popular. Irrespective of the type of processing the ceramic inlays are usually cemented with an adhesive technique by means of resin-based composite cement. This is supposed to be an efficient way to transfer and distribute to the surroundings stresses caused by occlusal forces (14). Since it is the fit achieved after cementation that is said to be most relevant for long-term clinical performance of fixed restorations (15), an evaluation of this variable was the main objective of the present study.

Measuring the distance between tooth substance and ceramic inlays after luting the restorations with composite resin cements gave rise to certain practical problems. One of the problems was the difficulty in determining the dividing line between inlay/luting agent and luting agent/enamel. Preliminary trials showed that it was difficult to detect the dividing-line even though a dark shade of cement had been chosen. By staining the resin cement with erythrosine the joint was made clearly visible. However, staining the cement revealed another overlooked problem—namely, that a very thin excess of cement or enamel bonding agent in some areas covered the inlay or enamel surfaces. This was especially pronounced on the occlusal surfaces. The excess made it difficult to detect the dividing line or could be mistaken for part of the width of the cement. Although the restorations had been finished with superfine diamonds and/or

Table 1. The distance (μm) between the inlay and tooth substance measured at occlusal, proximal, gingivoproximal, and internal locations and the standard deviations and ranges (within parentheses): mean values for 10 MOD inlays of each type

Type	Occlusal*	Proximal*	Gingivo-proximal*	Internal*
Cerec with sharp proximal boxes	195 ± 33 (65–590)	191 ± 65 (30–575)	202 ± 84 (35–575)	228 ± 68 (0–560)
Cerec with U-shaped proximal boxes	181 ± 39 (20–350)	167 ± 41 (30–390)	169 ± 50 (40–390)	224 ± 74 (20–560)
Celay	174 ± 43 (45–425)	169 ± 59 (20–390)	163 ± 62 (20–380)	190 ± 51 (0–770)
In-Ceram Spinell	152 ± 28 (40–310)	159 ± 42 (120–455)	165 ± 58 (20–455)	237 ± 68 (35–540)
Empress	103 ± 34 (0–415)	161 ± 58 (0–555)	181 ± 70 (0–555)	235 ± 63 (60–925)

* Definition of measuring points in accordance with Fig. 1a–c; Occlusal = measuring points A–F; Proximal = measuring points G–M; Gingivoproximal = measuring points I–M; Internal = measuring points N–T.

polished with SofLex disks before being measured, thin layers of excess cement still existed in some areas and were undetectable until the cement was stained. After being stained the excess could be carefully removed, and the cement re-stained before the gap was measured. Judging by experience from the present study, a thin excess of resin cement that has not been removed by polishing or/and clinical wear might be difficult to detect clinically, on replicas, and on models. The internal gap was measurable without staining of the cement.

The measured values in the present study were rounded off to the nearest 5 μm because the unavoidable presence of small irregularities of the inlay and enamel margins caused indistinctness in the transition from luting agent to enamel and/or restoration. Furthermore, although standardized as far as possible, the possibility cannot be excluded that the relationship between the position of the specimens and lighting in the microscope might slightly influence the measured values. These factors are small sources of error taken individually, but when added together, they have to be considered.

Comparisons between the values of the internal or marginal gap if measured before luting the inlays and the corresponding values obtained after luting could have been misleading because it was difficult to reproduce exactly the measuring from one occasion to another. The difficulties in reproducing the measuring from one occasion to another have recently been described by Bäck (1993) in a critical analysis of error sources in the determination of the fit of dental crown reconstructions (16). Furthermore, there were difficulties in placing the restorations in the cavities without any positioning errors after the cavities had been filled with the luting agent as compared with the position obtained if the inlays had been placed in the empty cavities. However, before the inlays in the present study were luted, the marginal adaptation and the overall fit were checked in the same manner as in a clinical standard procedure, and all inlays were judged to have been clinically acceptable for permanent placing in patients.

The 50 inlays studied in the present study were manufactured with four different techniques by four different individuals. It therefore seems reasonable to assume that there must have been differences in the initial fit of the inlays before luting. However, after the inlays had been luted, there were only slight differences between the mean gap widths obtained for the different inlay systems. This similarity may be due to the fact that the properties of the resin cement, classified as being of medium viscosity, influenced both the final internal and final marginal gap distances when the inlays were luted (17, 18). The reason the internal gap distance of the Celay inlays was closer to the gingivoproximal distances than the other inlays might be that no die spacer had been used and no grinding of either the gingival or the axial or pulpal walls of the inlays had been necessary during the production and the try-in procedure of the Celay inlays.

An interesting and clinically important observation in the present study was that when sharp and U-shaped proximal box corners for the Cerec inlays were compared, the U-shaped preparation gave a reduced marginal distance all around the margins. This is in accordance with results reported by Inokoshi et al. (19) and Hickel & Kunzelmann (20). That means that conventionally U-shaped or rounded proximal box corners can be recommended even for Cerec inlays, since the Cerec equipment seems to reproduce U-shaped or rounded box corners better than the sharp proximal box corners recommended by Mörmann & Brandistini (13). How sharp or rounded internal angles influence the fit at the internal angles of Cerec inlays has to be studied further.

With regard to the values of gap widths of ceramic inlays reported in previous studies comparisons of the results obtained by different investigators can be confusing. Variations in type of tooth preparation (19–21), in location and number of measuring points (7, 19, 20, 22–26), in measuring technique (20, 22, 24), and whether the fit was determined before or after luting the inlay will influence the results obtained. Furthermore, the type of resin cement used (7) and the method used for manufacturing the ceramic inlay concerned have to be taken into consideration when experimental data are compared.

However, on the basis of clinical experimental data the maximum film thickness that can be accepted is not clearly defined for ceramic inlays luted with composite resin cements. The film thickness determined in the present study varied within wide ranges, and distances up to almost 1 mm were observed. Thus, on the basis of the results of the present study it seems reasonable to assume that the film thickness will be wider in most cases for ceramic inlays luted with composite resin cements than for cast gold inlays luted with zinc phosphate cement (27–28) when a conventional cementation technique is used. This is because the properties of the luting agents seem to have a decisive influence on the final gap width. The inlays in the present study were all luted with a conventional technique, but further study is needed of the manner in which the use of ultrasonic insertion during cementation of ceramic inlays influences the marginal gap (29, 30). Furthermore, how will the overall preparation design and the initial fit of a ceramic inlay before luting influence the gap width? For example, will a wide initial gap make the outflow of a viscous resin cement easier and reduce the final gap width as when full crowns are vented (31)? Moreover, how does the film thickness influence the strength and longevity of composite resin cements? Thus, several matters remain to be studied before well-founded recommendations on the optimum fit and cementation technique for ceramic inlays can be given.

Acknowledgement.—This work was supported by the Swedish Medical Research Council (project 09447).

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Received for publication 7 April 1994
Accepted 27 June 1994