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Partial ceramic crowns. Influence of preparation design and luting material on margin integrity— a scanning electron microscopic study

Received: 13 February 2004 / Accepted: 27 May 2004 / Published online: 10 August 2004
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Abstract This in vitro study examines the effects of three preparation designs and different luting agents on the marginal integrity of partial ceramic crowns. One hundred forty-four extracted human molars were prepared according to the following preparation designs: A. Coverage of functional cusps, B. Horizontal reduction of functional cusps and C. Complete reduction of functional cusps. Partial ceramic crowns (Vita Mark II, Cerec 3 System) were bonded to the cavities with: Variolink II/Excite (Vivadent), Panavia F/ED primer (Kuraray), Dyract/Prime and Bond NT (Detrey/Dentsply), and Fuji Plus/GC cavity conditioner (GC). The specimens were exposed to thermocycling and mechanical loading. Marginal adaptation was assessed on replicas using quantitative margin analysis in the scanning electron microscope (SEM). Significant differences were observed between the preparation designs in general. Coverage of functional cusps with preparation of butt joints and use of Variolink as luting material showed a tendency toward the lowest values for compromised adhesion, especially within the dentin. Significant differences could be determined between luting systems: resin-modified glass ionomer cement (RMGIC) caused fracture of the restorations and revealed higher values than all other luting materials for compromised adhesion at ceramic-luting agent and tooth-luting agent interfaces. The dentin-luting material interface, in general, showed higher percentages of compromised adhesion (38–100%) than enamel- and ceramic-luting material interfaces (0–30%). In conclusion, the SEM data indicate that, with adhesively bonded partial ceramic crowns, retentive preparation is not contraindicated and the choice of luting material is more relevant

than the preparation design. Margins below the cemento-enamel junction reveal significant loss of adhesion in spite of adhesive luting techniques. The RMGIC cannot be recommended as a luting material for feldspathic partial ceramic crowns.

Keywords Feldspathic porcelain · Luting agents · Margin analysis · Partial ceramic crowns · Preparation design

Introduction

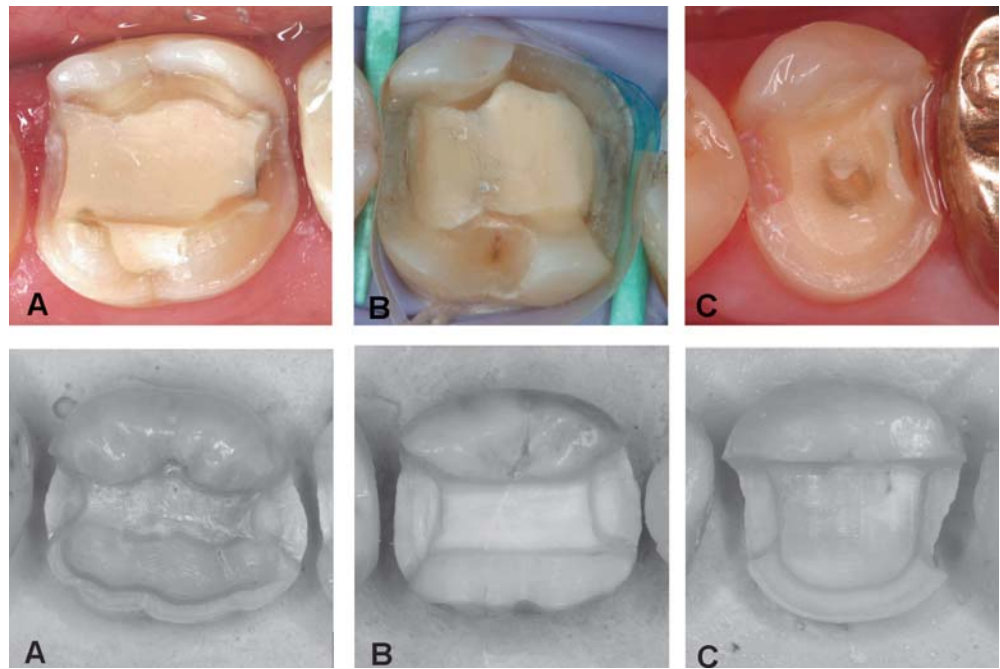
Today, dental treatment procedures are increasingly governed by factors such as biocompatibility of restorative materials, patients' demands for esthetics, and a conservative approach to minimize loss of tooth structure [30]. Dental ceramics meet these demands more than other currently available dental materials. The clinical success of ceramic inlays has been well documented in the literature [9, 10, 28, 35, 37], and the technique is recognized throughout the dental profession [24, 26]. Feldspathic ceramic materials with improved mechanical characteristics to minimize crack propagation are available [24, 27]. The survival rate of ceramic inlays has been reported to be in the range of that of cast gold restorations and amalgam fillings [7, 25].

Although caries is declining in many industrialized countries, there is still the demand for more complex restorations from a substantial number of patients [22, 24]. Data in the literature suggest that ceramic inlays used in the restoration of extensively damaged teeth with the proximal margin in dentin reveal a significant, time-dependent increase in marginal deterioration [16] and require further clinical evaluation [20]. Thus, the esthetic restoration of extensive cavities may be either achieved with traditional crowns of porcelain fused to metal or with all-ceramic crowns fabricated from high-strength materials such as aluminum oxide or zirconium oxide ceramics. However, crown preparation is associated with a considerable loss of sound tooth tissue, and access to restoration margins is critical [24, 36].

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Fig. 1 Clinical examples (*top row*) and the according experimental preparation designs (*bottom row*) suggested for PCC. *A* retentive design preparation: coverage of functional cusps and preparation of a butt joint. *B* adhesive onlay or overlay preparation: functional cusp with horizontal bevel. *C* Complete reduction of functional cusp and butt joint. Non-functional cusps were not included in the preparation



With respect to tissue-conserving tooth preparation, partial ceramic crowns (PCC) may be considered an alternative to extended ceramic inlay restorations on the one hand [16] and to full-coverage crowns on the other [36]. According to the German Dental Association [21], onlay or overlay restorations are defined as partial crowns when one or more cusps are restored. Limited data in the literature on the clinical behavior of PCC indicate the suitability of this approach [16, 36]. Reiss and Walther [22] found that the number of extended PCC restorations with the replacement of up to four cusps, increased during their 10-year observation period of CAD/CAM-fabricated ceramic restorations. Felden et al. [7] showed a survival probability of 55% for 7 years in a retrospective clinical investigation for PCC fabricated from Dicor glass ceramic. In a second investigation, PCC fabricated from the Empress I all-ceramic system showed a 7-year survival probability of 81% [8]. In addition, the survival rate of cast gold alloy partial crowns, the gold standard for posterior restorations, was shown to be statistically not superior to that of partial ceramic crowns when respective longevity for up to 7 years in clinical use was compared [38]. In a 5-year follow-up of restorations with extensive dentin- and enamel-bonded ceramic coverage, van Dijken et al. [36] reported a clinical success rate of 93.4% for PCC in vital teeth.

In the context of using PCC to conserve sound tooth structure in the restoration of extensively damaged teeth, three factors have to be considered: cavity preparation design, type of ceramic material and manufacturing process, and type of luting system.

With respect to cavity preparation, three basic concepts for PCC design have been suggested in the literature. The traditional preparation design utilizes a conventional retention form, evolving from the need for ad-

equate retention required by the limitations of traditional cements, or by technical and mechanical demands determined by restorative materials such as cast gold alloys (Fig. 1, A) [3, 13]. Based on the efficacy of the concept of bonded ceramic restorations, it has been stated that the traditional rules and principles of preparation may no longer be applicable. It has been suggested that PCC preparation can be performed with less emphasis on the retentive form, involving only a horizontal reduction of occluding cusps (Fig. 1, B) [15] or—even less restrictive—a merely defect-orientated preparation. In the latter, the retention of all-ceramic restorations depends totally on the bond to the underlying dentin and any available enamel mediated by an adhesive luting system (Fig. 1, C) [36].

With conventional feldspathic ceramics, the adhesive technique is crucial for successful bonding of the ceramic restoration, as it allows for a micromechanical bond between tooth structures, composite resin luting agent, and ceramic. Light-, dual-, and chemically-cured composite resin luting materials have been advocated [1, 29, 36]. Recently, light-cured glass ionomer cements and compomer cements have been suggested as alternative luting materials [23, 33], especially with respect to restorations with margins below the cemento-enamel junction (CEJ).

The purpose of this *in vitro* study was to evaluate the influence of different preparation designs for PCC and of different luting agents on marginal integrity before and after thermocycling and mechanical loading (TCML). It was hypothesized that both, preparation and luting agent would affect marginal integrity.

Fig. 2 Flow chart: methods and materials

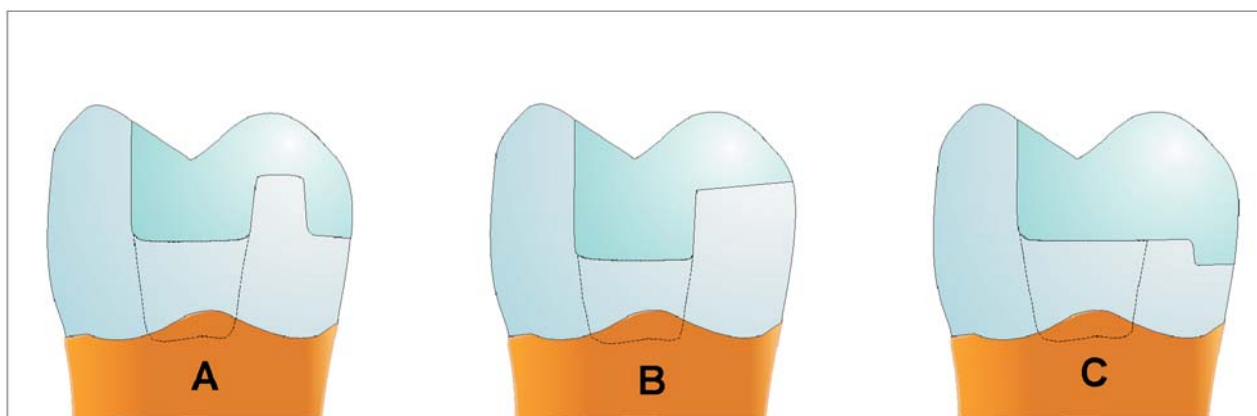
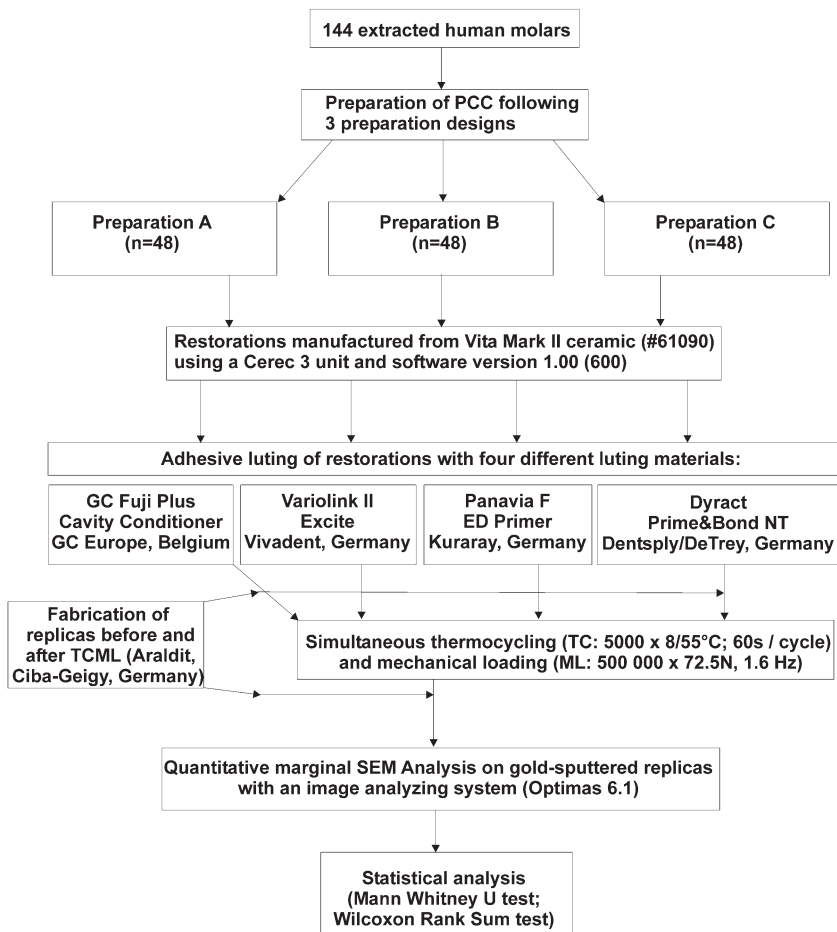


Fig. 3 Schematic drawing of preparations A–C, representing a midline cut in vestibulo-oral direction. (A) Coverage of functional cusps/butt joint preparation, (B) horizontal reduction of functional

cusps, and (C) complete reduction of functional cusps/butt joint preparation. *Dotted lines* indicate proximal boxes below the CEJ

Methods and materials

Sample preparation

Figure 2 summarizes the procedures followed in the present study. One hundred forty-four extracted human molars, which had been stored in chloramine solution from the time of extraction, were cleaned, mounted in Palavit G acrylic resin (Kulzer, Wehrheim,

Germany), and stored in physiological saline solution until use. The teeth were assigned randomly to three groups of 48 specimens each. Diamond burs (Cerinlay Set, Intensiv) (Viganello, Lugano, Switzerland) in a high-speed handpiece with sufficient water cooling were used to perform one of the following preparations on each tooth (Fig. 3):

Preparation A

Coverage of functional cusps (oral cusps in upper molars, buccal cusps in lower molars) plus butt joint preparation

Preparation B

Horizontal reduction of functional cusps

Preparation C

Complete reduction of functional cusps plus butt joint preparation

Nonfunctional cusps were not covered; proximal margins were placed 1 mm below the CEJ within cementum/dentin. Internally, rounded line angles were prepared. The CAD/CAM method (Cerec 3) (Sirona, Bensheim, Germany) was used to construct and machine-mill the partial ceramic crowns. Mark II ceramic blocks (Vita, Bad Säckingen, Germany) were used to fabricate the PCC using the Cerec 3 system and corresponding software (Sirona Cerec 3 software version 1.0). Following try-in and adjustment to the prepared cavities, the PCC were inserted using one of the following luting material/bonding system combinations (12 specimens each per luting system and preparation design):

VL: Variolink II/Excite (Vivadent, Schaan, Liechtenstein) dual-cured composite resin luting agent

PA: Panavia F/ED primer (Kuraray, Japan) dual-cured composite resin luting agent

DY: Dyract/Prime and Bond NT (Detrey/Dentsply, Konstanz, Germany) compomer

FU: Fuji Plus (GC Europe, Leuven, Belgium) chemically cured resin-modified glass-ionomer cement (RMGIC) used with GC cavity conditioner

To match the clinical situation as closely as possible, the restorative procedures were performed in a device simulating proximal contact to adjacent teeth. Clear matrix bands (Hawe Neos, Bioggio, Switzerland) and light-reflecting wedges (Hawe Neos) were used to reduce excess luting material and enhance light curing in proximal areas. Luting material was applied to the cavity surfaces following adhesive conditioning of tooth substances and PCC surfaces. The luting procedures are summarized in Table 1.

Excess luting material was removed prior to curing. Following insertion procedures, finishing was performed with Komet finishing diamonds (Brasseler, Lemgo, Germany) and the restorations were polished with Sof-Lex flexible discs (3M, St. Paul, Minn., USA.). Before TCML, samples were stored in physiological saline solution at 37°C for 24 h. Prior to and after TCML, Impregum impressions (Espe, Seefeld, Germany) were taken for the fabrication of epoxy replicas (Araldit) (Ciba-Geigy, Switzerland). The samples were exposed to thermocycling (5,000×8 at 55°C and 30 s/cycle) and mechanical loading (500,000×72.5 N at 1.6 Hz) simultaneously.

Quantitative scanning electron microscopic analysis

The replicas representing the specimens before and after TCML were subjected to quantitative margin analysis at 200× magnification in a Stereoscan 240 scanning electron microscope (SEM) (Cambridge Instruments, Nussloch, Germany) using the Optimas image analyzing system (Stemmer, Munich, Germany). Occlusal, vestibular, and proximal restoration margins (Fig. 4) registered on the replicas were included in the SEM evaluation. Tooth-to-luting agent (LA) and ceramic-to-LA interfaces were evaluated separately. The following criteria were used to describe margin quality.

- Perfect margin (PM): perfect adhesion and continuous adaptation at the ceramic-LA or tooth-LA interface
- Marginal imperfections (MI): no gap, but marginal imperfection (i.e., excess luting material, positive or negative ledges) due to handling of the luting agent
- Gap formation (GF): a clearly visible loss of adhesion between luting agent and ceramic or tooth structure
- Marginal expansion (ME): hygroscopic expansion at the tooth-composite interface; none of the above criteria can be applied.

Table 1 Luting materials, cavity/ceramic conditioning, and luting procedures

Luting material	Fuji Plus	Variolink II	Panavia F	Dyract
Resin-modified glass ionomer (no. 0006212, GC Europe, Belgium) Conditioning of ceramic	High viscosity, composite luting agent (no. B5306, Vivadent, Germany) Ceramics Etch gel (no. 041654, Vita, Germany) 60 s, followed by rinsing with water	Composite luting agent (paste A no. 00104A, paste B no. 00005A, Kuraray, Germany) Ceramics Etch gel (no. 041654, Vita, Germany) 60 s, followed by rinsing with water Monobond S (no. C24280, Vivadent, Germany) applied and dried after 60 s	Compomer material (no. 0108000448, Dentsply/DeTrey, Germany) Ceramics Etch gel (no. 041654, Vita, Germany) 60 s, followed by rinsing with water Porcelain bond activator (no. 0007171, Kuraray, Germany) mixed with Clearfill SE bond primer (no. 41116, Kuraray, Germany) applied and blow-dried	Ceramics Etch gel (no. 041654, Vita, Germany) 60 s, followed by rinsing with water Monobond S (no. C24280, Vivadent, Germany) silane treatment
Conditioning of cavity	GC cavity conditioner (no. 0010201, GC Europe, Belgium) 20 s, followed by rinsing with water and drying of cavity	Total Etch (no. D05082, Vivadent, Germany) dentin 20 s, enamel 40 s, followed by water spray and gentle blow-drying Excite (no. C15056, Vivadent, Germany) application, after 20 s gentle blow drying, light curing for 20 s	Total Etch (no. D05082, Vivadent, Germany) dentin 20 s; enamel 40 s, followed by water spray and gentle blow-drying ED primer liquid A (no. 00103B, Kuraray, Germany) ED Primer Liquid B (no. 00110B) mixed, applied for 60 s, gentle blow drying, light curing for 20 s	Conditioner 36 (no. 0103001067, Dentsply/DeTrey, Germany) dentin 20 s, enamel 40 s, followed by water spray and gentle blow-drying Prime and Bond NT (no. 0011000736, Dentsply/DeTrey, Germany) applied for 20 s, gentle blow drying, light curing for 20 s
Curing mode	Chemical curing with Fuji Coat LC (no. 0007171, GC Europe, Belgium) placed on restoration margins and light-cured for 10 s	Dual-curing (light application for 40 s from each aspect)	Dual curing (light application for 40 s from each aspect) Oxyguard II (no. 00325B, Kuraray, Germany) placed on restoration margins	Light-curing (light application for 40 s from each aspect)

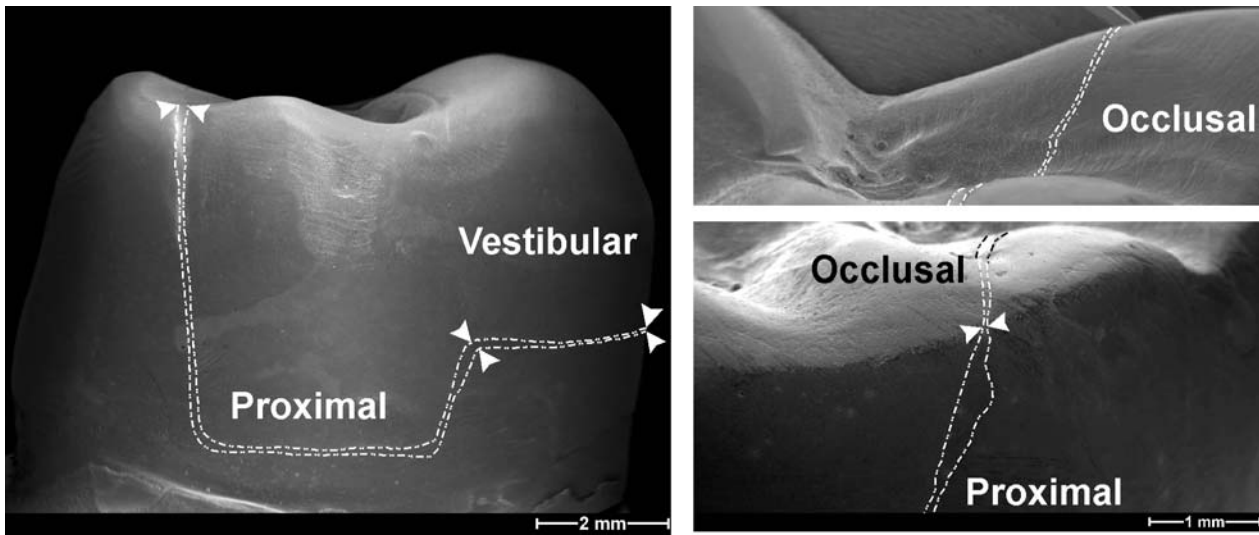


Fig. 4 Scanning electron microscopic picture indicating occlusal, vestibular, and proximal restoration margins. Restoration margins (ceramic- and tooth-luting composite resin interfaces) are indicated by *dotted lines*

The criteria were assigned to the corresponding sections of each interface and calculated as percentages of the entire length of the restoration margin examined. Marginal expansion and GF represent areas of compromised adhesion, as has been reported in the literature [34]. Percentages of GF and ME were added, and the percentage of compromised adaptation (CA) was calculated and selected as a descriptive value representing the extent of marginal deterioration at each interface. The results presented here refer to the criterion CA.

Statistical analysis

Nonparametric statistical analysis was considered appropriate for analyzing the data because of the lack of normal distribution. Medians and 25–75% percentiles for each of the different criteria were determined for all interfaces separately. Additionally, all SEM data were pooled for each preparation design and luting system by TCML and by interface, respectively, to determine the influences of preparation design and luting material in general. Statistical analysis was performed using Mann-Whitney U and Wilcoxon's rank sum tests (PC+ version 6.0 software) (SPSS, Chicago, Ill,

USA) for pairwise comparisons among groups. The level of significance was set at $\alpha=0.05$. For evaluating the influence of preparation design and luting material in general, the level of significance was adjusted to $\alpha^*(k)=1-(1-\alpha)^{1/k}$ by application of the error rates method ($k = n$ of paired tests performed).

Results

With VariolinkII/Excite, lowest values for compromised adaptation were found at the ceramic-LA and enamel-LA interfaces, with medians ranging from 0% to 1% (Fig. 5). More important were the comparatively high CA values at the dentin-LA interface, ranging between 57% and 86% before TCML and between 38% and 92% after TCML. Preparation A (median before TCML 57%, after TCML 38%) revealed significantly lower CA values at the dentin-LA interface than preparations B (before TCML 86%,

Fig. 5 Compromised adaptation (GF plus ME in percent) with VariolinkII luting material plus Excite at the ceramic (*Ce*), enamel (*En*), and dentin (*De*) interfaces for preparations A, B, and C before (1) and after (2) TCML (median and 25–75% quartiles). Bars indicate significant differences. * $P \leq 0.05$; ** $P \leq 0.01$

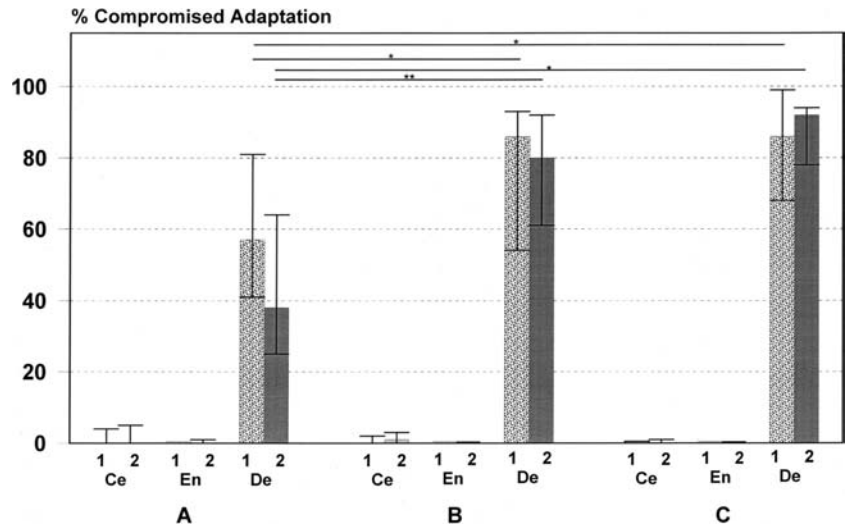


Fig. 6 Compromised Adaptation (GF plus ME in percent) with luting material Panavia F/ED Primer at the ceramic (*Ce*), enamel (*En*), and dentin (*De*) interfaces for preparations A, B and C before (1) and after (2) TCML (median and 25–75% quartiles). Bars indicate significant differences. * $P \leq 0.05$; ** $P \leq 0.01$

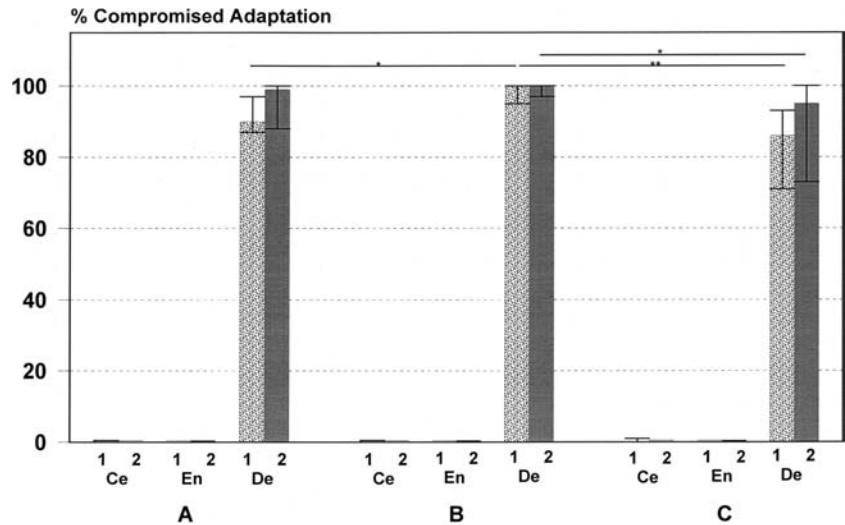
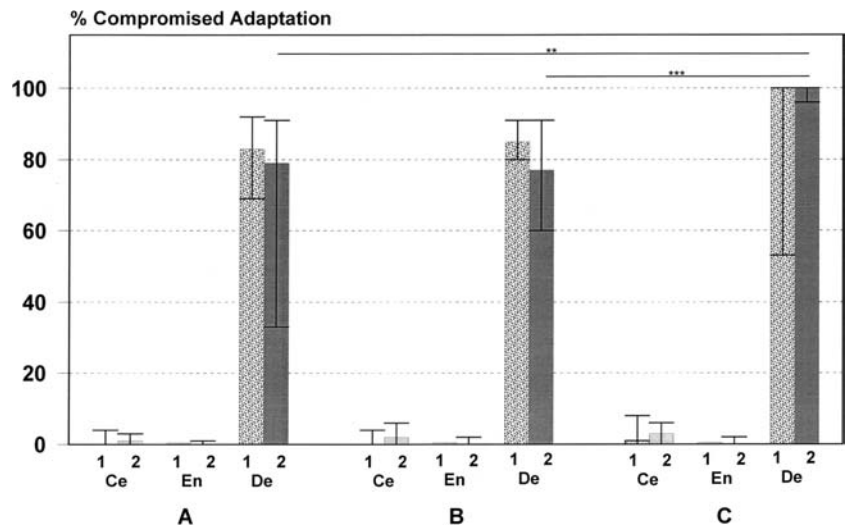


Fig. 7 Compromised adaptation (GF plus ME in percent) with Dyract luting material plus Prime and Bond NT at the ceramic (*Ce*), enamel (*En*), and dentin (*De*) interfaces for preparations A, B, and C before (1) and after (2) TCML (median and 25–75% quartiles). Bars indicate significant differences. ** $P \leq 0.01$, *** $P \leq 0.001$



after TCML 80%) and C (before TCML, 86%, after TCML 92%) both before and after TCML ($P \leq 0.05$). VariolinkII/Excite showed a tendency toward the lowest CA of all luting materials used, and preparation design A revealed the lowest CA at the proximal dentin interface.

With Panavia/ED primer, lowest values for CA were found at the ceramic-LA and enamel-LA interfaces (median 0%) (Fig. 6). Again, the dentin-LA interface showed much higher CA values, ranging between 86% and 100%. Preparation B (before TCML 100%, after TCML 100%) exhibited the highest CA values at the dentin-LA interface, followed by preparations A (before TCML 90%, after TCML 99%) and C (before TCML 86%, after TCML 95%). This difference was statistically significant for preparations A ($P \leq 0.05$) and C ($P \leq 0.01$) before TCML and for preparation C ($P \leq 0.05$) after TCML.

With Dyract/Prime and Bond NT, the lowest CA values were found at the ceramic-LA (median 0–3%) and enamel-LA interfaces (median 0%) (Fig. 7). Again, higher CA values ranging between 77% and 100% were found at the dentin-LA interfaces, where preparations A

(before TCML 83%, after TCML 79%) and B (before TCML 85%, after TCML 77%) showed lower values than preparation C (100% both before and after TCML). After TCML, the difference between preparations A and B and preparation C was statistically significant ($P \leq 0.01$).

With Fuji Plus/GC cavity conditioner, 12 restoration fractures (Fig. 8) occurred either prior to TCML after 24-h storage in saline solution at 37°C ($n=5$) or following TCML ($n=7$). With respect to preparation design, preparation A revealed six fractures and preparations B and C three fractures in each group. Quantitative SEM data were not recorded for fractured specimens. With Fuji Plus/GC, lowest CA values were found at the ceramic-LA interface, ranging between 7% and 30% (Fig. 9). At the ceramic-LA interface, preparation C (before TCML 7%, after TCML 8%) exhibited lower CA values than preparations A (before TCML 17%, after TCML 18%) and B (before TCML 28%, after TCML 30%). Before TCML, this difference was statistically significant for preparations A ($P \leq 0.05$) and B ($P \leq 0.01$), and after TCML the difference was statistically significant for

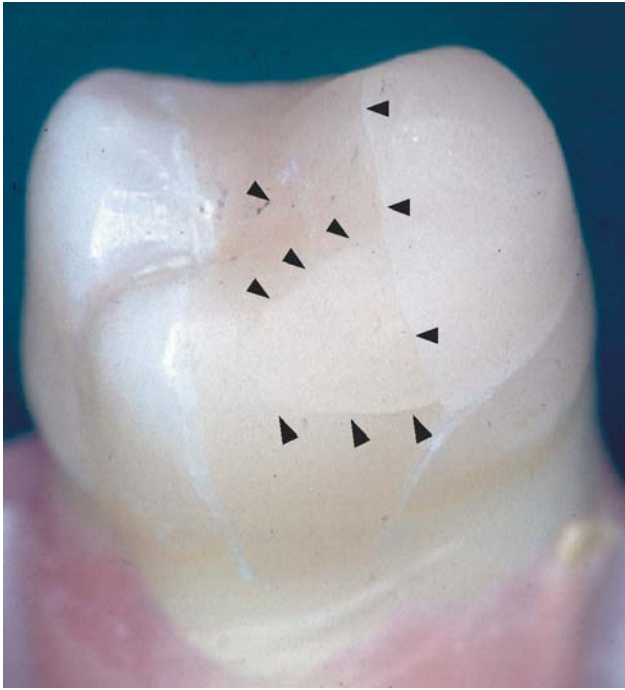


Fig. 8 Fracture of restoration inserted with RMGIC. Arrows indicate fracture lines

preparation B ($P \leq 0.01$). Again, the highest CA values, ranging between 95% and 100%, were recorded at the dentin-LA interfaces.

Compromised adaptation values pooled for preparation design and luting material by TCML and by interface (ceramic-LA and tooth-LA) are shown in Fig. 10. With respect to preparation design, all preparations revealed CA values ranging from 1% to 3% at the ceramic-LA interface and from 19% to 28% at the tooth-LA interface. Application of the error rates method showed a significant influence of preparation design in general, with preparation A revealing significantly lower CA values than preparations B and C. With respect to the type of luting

material, the data revealed that use of RMGIC resulted in marginal deterioration at both interfaces, with CA values ranging between 12% and 29%. The RMGIC exhibited higher overall CA values than both the composite resin and compomer luting materials. The former showed higher CA values at the tooth-LA interface than the compomer, whereas the latter showed higher CA values at the ceramic-LA interface. Application of the error rates method showed a significant influence of luting material in general.

Discussion

In the present study, quantitative SEM margin analysis was chosen to determine the degree of marginal deterioration. The criterion CA, adding gap formation and marginal expansion percentages, both signs of the loss of marginal integrity, serves as a descriptive value for the amount of marginal deterioration in order to report a “worst case” scenario rather than percentages of perfect margins [34].

To evaluate the influence of preparation design and luting material in general, CA values were calculated for ceramic-LA and tooth (dentin plus enamel)-LA interfaces separately and then pooled for either preparation design or luting material by TCML and by interface. Regarding the correlation of in vitro and in vivo situations, Krejci and Lutz [14] indicated that 120,000 chewing (loading) cycles approximated 6 months of clinical use in their in vitro setup, and the settings in the present study were regarded as sufficient to approximate 2–2.5 years of clinical use.

The three preparation designs investigated were chosen based on PCC preparation concepts described in the literature [3, 13, 15, 36]. All three include the coverage of functional cusps. It has been reported that MOD (Mesial-Occlusal-Distal) preparations may weaken teeth by approximately 59% (premolars) [31]. Enhancement of fracture resistance by adhesively luted inlay restorations is discussed controversially in the literature [11, 16, 17,

Fig. 9 Compromised adaptation (GF plus ME in percent) with Fuji Plus luting material plus GC conditioner at the ceramic (Ce), enamel (En), and dentin (De) interfaces for preparations A, B, and C before (1) and after (2) TCML (median and 25–75% quartiles). Bars indicate significant differences. * $P \leq 0.05$, ** $P \leq 0.01$

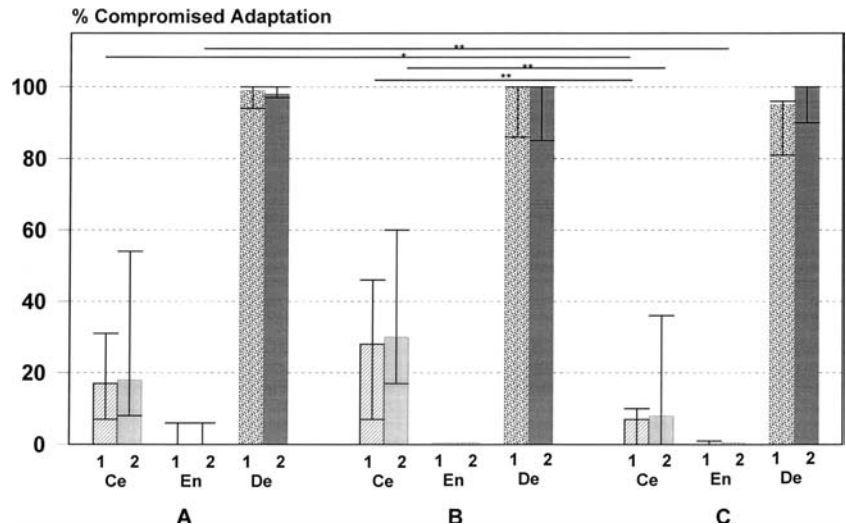
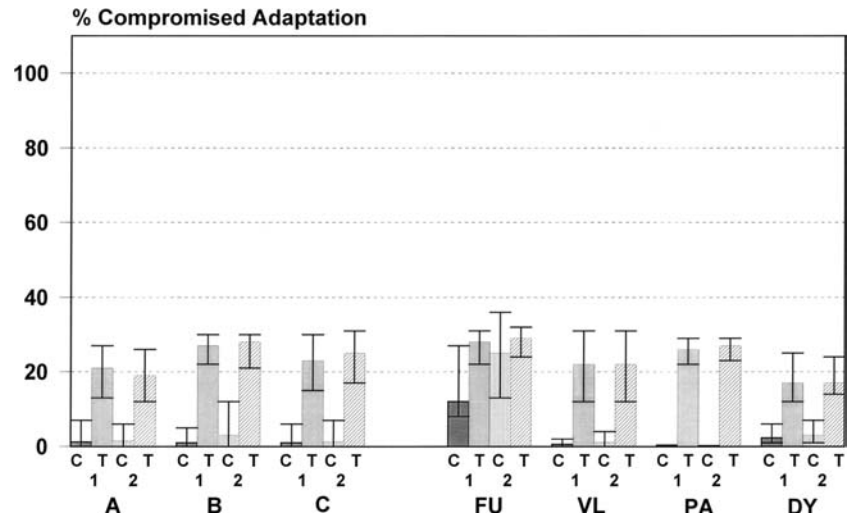


Fig. 10 Compromised adaptation (GF plus ME in percent) pooled for preparation designs A, B, and C and luting materials (FU Fuji Plus, VL Variolink, PA Panavia F, DY Dyract) at the ceramic-LA interface (C) and tooth-LA interface (T) before (1) and after (2) TCML (median and 25–75% quartiles)



19, 20]. Preparation A represents a traditional design for retentive cavity preparation described for cast gold alloy partial crowns and modified to suit ceramics as a restorative material, as reported by Jedynakiewicz and Martin [13]. However, Broderson [3] indicates that the retentive coverage of occluding (functional) cusps is considered to create a high number of stress points in the ceramic restoration. Preparation B merits the advantages of adhesive luting procedures, which allow a less invasive approach in cavity preparation and employ mere horizontal reduction of the functional cusps [15]. In preparation design C, retention of the restoration was reported to rely mainly on the adhesive bond between tooth tissues, luting agent, and ceramic and not upon retentive elements in the cavity geometry [36].

Nonfunctional cusps were not included in the preparation, in accordance with the tooth-conserving approach based on reinforcing tooth stability by adhesive luting procedures, assuming sufficient thickness of the remaining nonfunctional cusps [16]. Restoration of extensively damaged teeth involves restoration margins below the CEJ, within dentin/cementum, and thus proximal restoration margins have been extended below the CEJ [32, 36].

A machinable feldspathic ceramic was used for fabricating the restorations by means of a CAD/CAM process (Cerec 3). The prefabricated ceramic blocs are industrially sintered and of high homogeneity, reducing the initiation and propagation of microcracks [27]. The Cerec method is recognized in the scientific dental literature. A survival rate of 95.5% for bonded all-ceramic inlays and PCC for up to 10 years has been documented [2, 22].

With respect to the influence of preparation design, the results of the present study indicate a statistically significant influence of preparation design when CA data are pooled. Significantly better marginal adaptation was found with preparation A at the tooth-LA interface after TCML (19%) than with designs B (28%) or C (25%). When interfaces and luting agents were evaluated separately for each preparation, preparation design A (reten-

tive) also revealed a tendency toward the lowest values of marginal deterioration (CA) when combined with VariolinkII/Excite as the luting system, especially concerning margins within dentin/cementum.

Preparation and cavity design for adhesively luted PCC are factors which have not been extensively addressed in the literature so far. In an in vitro study, Burke [4] reported no differences between varying degrees of tooth preparation to enhance fracture resistance of dentin-bonded crowns. Van Dijken et al. [36] found no statistically significant differences between four preparation designs in their 5-year follow-up of dentin/enamel-bonded ceramic coverages.

Within the limitations of the present study, the concern addressed by Broderson [3] with respect to retentive coverage of functional cusps creating a high number of stress points in the ceramic restoration cannot be confirmed. This may be attributed to the CAD/CAM processing of an industrially fabricated ceramic preform used here, whereas the findings of Broderson refer to the use of a castable glass ceramic. The only indication that retentive coverage may create stress in the ceramic restoration can be found in the sample luted with resin-modified glass ionomer cement, the RMGIC causing more restoration fractures in specimens with preparation A than with preparations B or C. However, with respect to findings in the literature, the reason for the observed restoration fractures in the RMGIC sample ought to be attributed to the nature of the luting agent rather than preparation design [6, 18].

With respect to the luting material, this study shows that the use of RMGIC exhibited the most deleterious effect, causing fracture of the PCC either prior to TCML after 24-h storage or following TCML. The RMGICs have been advocated for the insertion of ceramic inlays [33, 37], but anecdotal reports based on clinical observations have linked them to postcementation fracture of all-ceramic crowns. Leevailoj et al. [18] investigated the fracture incidence of all-ceramic crowns cemented with RMGIC luting materials and other luting agents. They

demonstrated restoration fractures in two of the three RMGICs they investigated. Feilzer et al. [6] observed a conversion of contraction stresses into expansion stresses in RMGICs, resulting in a buildup of compressive strength in the long term. They indicated that it is of paramount importance that the expansion of RMGIC be limited and not grow to unacceptable values, which might damage the restoration or tooth structure as in the present investigation.

The two composite resin luting agents exhibited CA values in the same range. VariolinkII/Excite in combination with preparation A revealed a trend to the lowest marginal deterioration, especially within the dentin. Pooled CA values for luting materials showed significant differences between the RMGIC and the two luting composite resins, Variolink II or Panavia F, and the compomer Dyract. These findings are in accordance with data on composite resin luting materials and a compomer reported in the literature for inlays [28, 33] and onlays [36].

Proximal restoration margins within dentin/cementum revealed severe marginal deterioration compared to enamel- and ceramic-luting composite interfaces. The data are in accordance with results reported in the literature for inlay restorations [29] and onlay restorations [12]. Those authors reported that cervical restoration margins within dentin revealed significantly lower percentages of perfect margins than within enamel. Lang et al. [16] found a time-dependent increase in marginal deterioration for large inlay restorations with proximal margins in dentin in a clinical investigation comparing extended ceramic inlay preparations with PCC. They concluded that coverage of the weakened cusps as performed in PCC restorations resulted in indirect stressing of tooth structure and reduced marginal deterioration of the adhesive bond. This was confirmed by van Dijken et al. [36] but is not in accordance with the findings of this examination. Here, the length of enamel margins available for adhesive bonding considerably exceeded the length of the dentinal margins involved at the proximal boxes, which may be one reason for the discrepancy between these results and those reported by Lang et al. and van Dijken et al. [16, 36].

With respect to the influence of luting material, the findings of the present study on marginal adaptation of PCC are in accordance with previous data on microleakage and internal adaptation of PCC [5]. Statistically significant differences were found between luting materials, composite resin luting agents revealing lower microleakage and better internal adaptation than compomer and RMGIC. Regarding the influence of preparation design, no differences between preparations A, B, and C were found when internal adaptation was previously evaluated by dye penetration [5]. However, in the present study, preparation A revealed an external marginal adaptation superior to that of preparations B and C, indicating the importance of evaluating both external marginal adaptation by SEM analysis and internal adaptation by dye penetration.

Conclusions

In conclusion, retentive preparation design is not contraindicated with adhesively bonded PCC. However, the choice of luting material is more relevant than preparation design. Margins below the CEJ are critical, in spite of consequent application of adhesive luting techniques and improved bonding systems. Resin-modified glass ionomer cement cannot be recommended as a luting material for CAD/CAM-machined, feldspathic PCC.

Acknowledgements We wish to express our thanks and appreciation to Prof. Dr. Loys J. Nunez, Memphis, Tennessee, for his constructive criticism and advice while preparing the manuscript. We also thank all manufacturers for the generous donation of materials.

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