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ORIGINAL ARTICLE

Effect of proximal box elevation with resin composite on marginal quality of ceramic inlays in vitro

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Abstract
Objectives The objective of this study was to evaluate the marginal quality and resin–resin transition of milled CAD/CAM glass–ceramic inlays in deep proximal cavities with and without 3-mm proximal box elevation (PBE) using resin composites before and after thermomechanical loading.
Materials and methods MOD cavities with one proximal box beneath the cementoenamel junction were prepared in 48 extracted human third molars. Proximal boxes ending in dentin were elevated for 3 mm with different resin composites (RelyX Unicem, G-Cem, and Maxcem Elite as self-adhesive resin cements and Clearfil Majesty Posterior as restorative resin composite in one or three layers bonded with AdheSE) or left untreated. IPS Empress CAD inlays were luted with Syntac and Variolink II (n=8). Marginal quality as well as the PBE–ceramic interface were analyzed under an SEM using epoxy resin replicas before and after thermomechanical loading (100,000×50 N and 2,500 thermocycles between +5°C and +55°C).
Results Bonding glass–ceramic directly to dentin showed the highest amounts of gap-free margins in dentin (92%, $p<0.05$). Bonded resin composite applied in three layers achieved 84% gap-free margins in dentin; PBE with self-adhesive resin cements exhibited significantly more gaps in dentin ($p<0.05$).
Conclusions With a meticulous layering technique and bonded resin composite, PBE may be an alternative to ceramic bonding to dentin. Self-adhesive resin cements seem not suitable for this indication.
Clinical relevance For deep proximal boxes ending in dentin, a PBE may be an alternative to conventional techniques.

Keywords Dentin bonding · Resin composites · Glass–ceramic · Margin relocation · Self-etch · Ceramic inlays · Etch-and-rinse

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Introduction

Dental ceramics are widespread for both crown restorations and for inlays and onlays [1–13]. For leucite-reinforced glass–ceramic IPS Empress which has been marketed in 1990, a sound database of clinical investigations is available today [10, 13, 14]. Facing clinical failures with this kind of restorations, fractures are the predominant failure scenario for all commercially available ceramics for inlay preparations [2, 9–11, 14]. Whereas class I restorations frequently suffer marginal fractures, class II inlays primarily fail due to bulk fractures [7, 10, 13, 15, 16]. There was always a certain amount of marginal deterioration detected clinically; however, in the majority of cases, this decrease in marginal performance was not crucial for long-term survival [3, 10, 13, 16, 17]. Also, cavity preparation design [18–20] is discussed to have a certain influence here besides the use of different luting procedures [21–23].

When ceramic restorations are inserted in cavities being completely surrounded by enamel, their clinical prognosis is excellent [4]. In deeper proximal boxes, clinical data are scarce, but still positive [13]. Nevertheless, the clinical problem with these areas is that rubber dam application may be as difficult as moisture control over a certain period of time, being considerably longer than with direct resin composite restorations [18]. It may be a possible answer to the problem of elevating deep proximal areas with a small amount of resin composite in order to facilitate rubber dam application and adhesive luting, as described by Dietschi et al. [24].

Therefore, the aim of the present in vitro study was to evaluate the effect of a proximal box floor elevation/margin relocation with resin composite on the marginal quality of mesio-occlusal-distal (MOD) leucite-reinforced glass–ceramic inlays. The null hypothesis was twofold: (1) that the kind of resin composite, i.e., bonded resin composites and self-adhesive resin cements, would have no influence on the marginal integrity of ceramic inlays in enamel and dentin and (2) that the number of increments would have no impact on the results as well.

Materials and methods

Specimen selection, involved materials, and tooth preparation

Forty-eight intact, non-carious, unrestored human third molars, extracted for therapeutic reasons, were stored in an aqueous solution of 0.5% chloramine T at 4°C for up to 30 days. The teeth were debrided of residual plaque and calculus and examined to ensure that they were free of defects under a light microscope at ×20 magnification. Standardized class II cavity preparations (MOD, 4 mm in width bucco-lingually at the isthmus, 3 mm in depth occlusally, 2 mm in depth at the bottom of the proximal box) were performed. Proximal margins were located 2 mm above the cementoenamel junction (CEJ) mesially and 2–3 mm below the CEJ at distal aspects (Fig. 1). Cavities were cut using coarse diamond burs under profuse water cooling (80-μm diamond, Two-Striper® Prep-Set, Premier, St. Paul, MN, USA) and finished with a 25-μm finishing diamond (Inlay Prep-Set, Intensiv, Viganello-Lugano, Switzerland). The inner angles of the cavities were rounded and the margins were not bevelled. In five of the six experimental groups, the deep proximal box was elevated with resin composite to reach the level of the opposing proximal box (proximal box elevation, PBE; Figs. 2, 3, and 4). The materials for PBE were RelyX Unicem (3M Espe, Seefeld, Germany), G-Cem (GC Europe, Leuven, Belgium), Maxcem Elite (Kerr, Orange, CA, USA), or Clearfi Majesty Posterior (Kuraray, Tokyo, Japan) in one or three layers being bonded with AdheSE (Ivoclar Vivadent, Schaan, Principality of Liechtenstein; Table 1). After placement of the different resin composites, the cavities were finished again. Due to the rounded appearance of the proximal box, the PBE resin composite parts were half-moon-shaped (Figs. 3, 4, and 5).

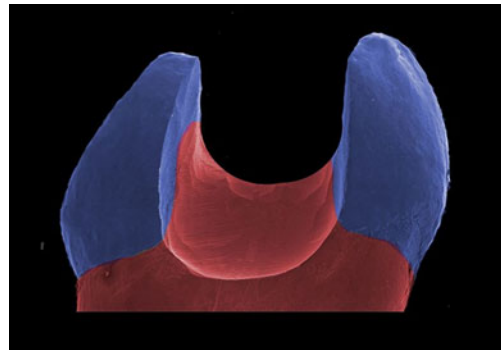

Fig. 1 Proximal box preparation with cervical margins in dentin (SEM image, ×20): dentin areas (*reddish*), enamel areas (*blue*)

Putty-wash impressions (Provil Novo, Heraeus Kulzer, Hanau, Germany) of the preparations were taken for laboratory milling of IPS Empress CAD glass–ceramic inlays (Absolute Ceramics, Leipzig, Germany) within 1 week after impression taking. The prepared teeth received temporaries (Telio inlay, Ivoclar Vivadent) for the time being unrestored and were then stored in distilled water at 37°C. After the milling procedures were finished, the fit of the inlays was evaluated and internal adjustments were performed using finishing diamonds in order to achieve a marginal gap of below 200 μm. In the deepest points of both proximal boxes, the width of the luting gap was measured under a stereo light microscope at ×100 (SV 11, Zeiss, Jena, Germany) with the inlays being non-luted. The cavities were then cleaned with pumice slurry and the PBE resin composite sandblasted

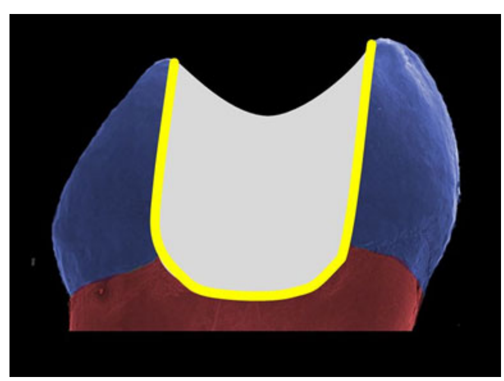

Fig. 2 Ceramic inlay (*white*) luted with resin composite (*yellow*) in the cavity of Fig. 1, i.e., the inlay is cervically bonded to dentin

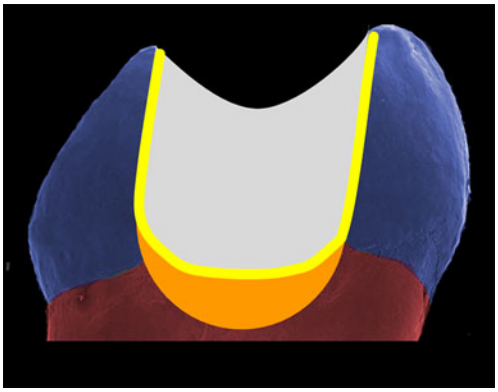

Fig. 3 Ceramic inlay (*white*) luted with resin composite (*yellow*) in the cavity of Fig. 1 after PBE with resin composite in a 2-mm layer. The inlay is cervically bonded to resin composite (*orange*). Due to the recommended round preparation of the proximal box, the PBE resin composite part is half-moon-shaped

(Rondoflex 50 µm, KaVo, Biberach, Germany). The internal surfaces of the ceramic inlays were pretreated with 5% hydrofluoric acid for 45 s (Ceramic Etch, Vita Zahnfabrik, Bad Säckingen, Germany), rinsed with air–water spray for 60 s, cleaned in an ultrasonic bath in 90% ethanol, dried, and then silanated with Monobond S for 60 s (Ivoclar Vivadent). Adhesive luting was performed with Syntac and Variolink II. Prior to polymerization, the luting composite was covered with glycerine gel (Airblock, Dentsply DeTrey, Konstanz, Germany) to prevent the formation of an oxygen-inhibited layer.

Adhesives and luting resin composite were polymerized with a Translux CL light-curing unit (Heraeus Kulzer, Dormagen, Germany). The intensity of the light was checked periodically with a radiometer (Demetron Research Corp., Danbury, CT, USA) to ensure that 800 mW/cm^2 was always exceeded during the experiments. The luting

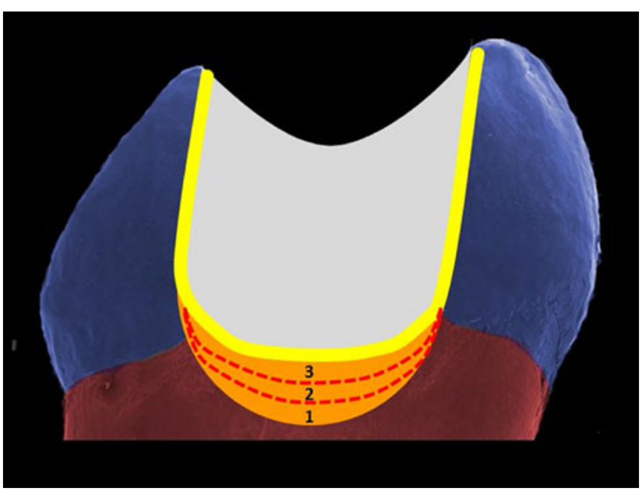

Fig. 4 Ceramic inlay (*white*) luted with resin composite (*yellow*) in the cavity of Fig. 1 after PBE in three consecutive increments of 1 mm each

composites were cured together with the adhesive with an overall curing time of 240 s per tooth. For seating and photopolymerization, the teeth were mounted in a phantom head (KaVo). Light curing started from mesial proximal at the dentin margins, went on clockwise, and ended occlusally.

Prior to the finishing process, visible overhangs were removed using a posterior scaler (A8 S204S, Hu-Friedy, Leimen, Germany). Margins were finished with fine finishing diamonds (Two-Striper, Premier) and flexible disks (SofLex Pop-on, 3M ESPE, St. Paul, MN, USA). Final polishing was conducted using felt disks (Dia-Finish E Filzscheiben, Renfert, Hilzingen, Germany) with a polishing gel (Brinell, Renfert, Hilzingen, Germany). After storage in distilled water at 37°C for 21 days, impressions (Provil Novo, Heraeus Kulzer) of the teeth were taken and a first set of epoxy resin replicas (Alpha Die, Schuetz Dental, Rosbach, Germany) was made for SEM evaluation. Again, the width of the luting gap was measured after placement as described above.

Functional loading in a chewing simulator

Thermomechanical loading (TML) of specimens was then performed in an artificial oral environment (“Quasimodo” chewing simulator, University of Erlangen, Germany). One specimen was arranged in one simulator chamber and obliquely occluded against a steatite (a multicomponent semi-porous crystalline ceramic material) antagonist (6 mm in diameter) for 100,000 cycles at 50 N at a frequency of 0.5 Hz. The specimens were simultaneously subjected to 2,500 thermal cycles between +5°C and +55°C by filling the chambers with water in each temperature for 30 s. The mechanical action and the water temperature within the chewing chambers were checked periodically to guarantee a reliable TML effect.

Analysis of marginal quality

After the completion of 100,000 mechanical loading and 2,500 thermal cycles, impressions of the teeth were retaken and another set of replica was made for each restoration. The replicas were mounted on aluminum stubs, sputter-coated with gold, and examined under a SEM (Leitz ISI 50, Akashi, Tokyo, Japan) as before at ×200 magnification. SEM examination was performed by one operator having experience with quantitative margin analysis who was blinded to the restorative procedures. The marginal integrity between resin composite and dentin was expressed as a percentage of the entire margin length in dentin. Marginal qualities were classified according to the criteria “continuous margin,” “gap/irregularity” (Fig. 7), and “not judgeable/artifact” according to a well-proven protocol relating margins in dentin,

Table 1 Materials under investigation

PBE: adhesive + resin composite	Components	Manufacturer
Syntac + Variolink II	Etchant: 35% phosphoric acid Primer: Maleic acid 4%, TEGDMA, water, acetone Adhesive: Water, PEGDMA, glutaraldehyde Heliobond: bisGMA, UDMA, TEGDMA Luting composite Base: bisGMA, TEGDMA, UDMA, fillers, ytterbium trifluoride, stabilizers, pigments Catalyst: bisGMA, TEGDMA, UDMA, fillers, ytterbium trifluoride, stabilizers, pigments, benzoyl peroxide	Ivoclar Vivadent, Schaan, Principality of Liechtenstein
RelyX Unicem	Self-etch cement Powder: Glass powder, silica, calcium hydroxide, pigment, substituted pyrimidine, peroxy compound, initiator Liquid: Methacrylated phosphoric ester, dimethacrylate, acetate, stabilizer, initiator	3M Espe, Seefeld, Germany
Maxcem Elite	Self-etch cement GPDM, comonomers with proprietary self-curing redox initiator, photoinitiator, stabilizer, inorganic fillers	Kerr, Orange, CA, USA
G-Cem	Self-etch cement Powder: Fluoro-alumino-silicate glass, initiator, pigment Liquid: urethane dimethacrylate, dimethacrylate, 4-mathacryloyloxiethyltrimellitate, distilled water, phosphoric acid ester monomer, silicon dioxide, initiator, inhibitor	GC Europe, Leuven, Belgium
AdheSE	Primer: phosphoric acid acrylate, dimethacrylate, initiators, and stabilizers in an aqueous solution Bond: 2-hydroxymethylmethacrylate, dimethacrylate, silicon dioxide, camphorchinone	Ivoclar Vivadent, Schaan, Principality of Liechtenstein
Clearfil Majesty Posterior	Resin composite: BisGMA, TEGDMA, ArDMA, 82–92 wt.% fillers	Kuraray, Tokyo, Japan

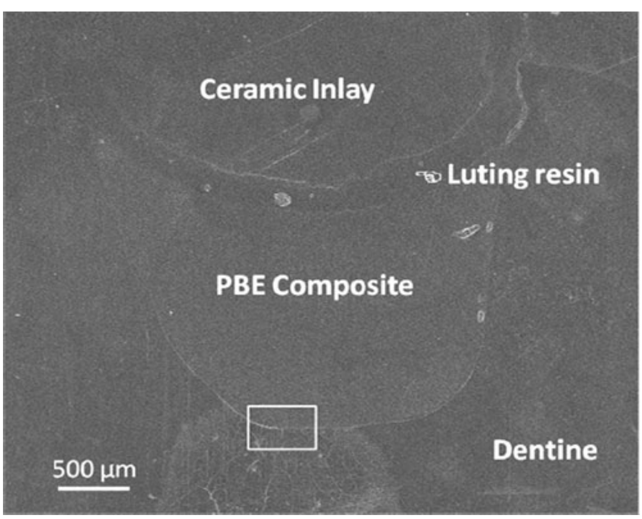

Fig. 5 SEM image of the cervical part of a PBE specimen. The ceramic inlay is bonded resin composite having been applied during the first session prior to impression taking

resin–resin transitions, and margins in enamel [25]. Afterward, the percentage "continuous margin" in relation to the individual judgeable margin was calculated as marginal integrity.

Statistical appraisal

Statistical analysis was performed using SPSS, version 14.0 for Windows XP (SPSS Inc., Chicago, IL, USA). As the majority of groups in each of the two investigations (i.e., enamel or dentin marginal integrity) did not exhibit normal data distribution (Kolmogorov–Smirnov test), non-parametric tests were used (Wilcoxon matched-pairs signed-ranks test, Mann–Whitney *U* test) for pairwise comparisons at the 95% significance level. Additionally, an adjustment according to Bonferroni–Holm was computed.

Results

The results of the study are displayed in Table 2. In all groups, TML resulted in a significant deterioration of marginal quality for both enamel and dentin margins ($p<0.05$; Wilcoxon matched-pairs signed-ranks test). Defects between the ceramic and luting resin composite ranged below 2% and were not subjected to further statistical treatment; defects between PBE composite and luting composite were also only observed in <2% of total transition lengths. Marginal quality in enamel was not different among groups ($p>0.05$). The measured luting gap widths were not significantly different for all luting systems, being between on average 205±21 µm ($p>0.05$, Mann–Whitney *U* test).

After TML, gap-free margins in dentin were 92% with the conventional luting technique, i.e., ceramic luted to dentin directly. Covering dentin with three consecutive layers of resin composite and bonding the ceramic inlay to the sandblasted resin composite achieved 84% gap-free margins and was significantly better than the other groups ($p<0.05$; Fig. 6). PBE with one layer of resin composite was equal to RelyX Unicem and superior to G-Cem and Maxcem Elite ($p<0.05$; Fig. 7).

Discussion

The aim of the present in vitro study was to evaluate the effect of a proximal box floor elevation/margin relocation with resin composite on the marginal quality of glass–ceramic inlays in dentin. It was investigated whether the kind of resin composite or the number of applied increments would have an effect on the marginal quality. The principal idea of PBE is not new; already in 2003, Dietschi et al. [24] published in vitro results of resinous margin relocations with different materials, showing that Tetric Flow may be an appropriate way to do so.

Due to the limited possibility to simulate all decisive and clinically relevant factors, the present study has not been designed to answer the complex topic of clinical survival; we exclusively focused on marginal quality in vitro as an indispensable prerequisite for clinical success [26, 27]. Simulation of intraoral conditions in a chewing simulator may predict clinical behavior in terms of marginal integrity [28]. Although the present investigation may be closer to the clinical situation than, e.g., bonding tests, the prospective clinical trial remains the final instrument to definitely answer the question regarding adhesive luting of ceramic inlays [11, 16, 17]. On the other hand, plane experimental questions like the present one are the predominant field for thorough in vitro testing of dental biomaterials.

Table 2 Results for MQ in dentin with and without PBE

PBE	MQ dentin initial, % gap-free (SD)	MQ dentin after TML, % gap-free (SD)
Maxcem Elite	94 (8)B	62 (14)D
RelyX Unicem	100A	71 (10)C
G-Cem	97 (4)B	64 (12)D
Clearfil 1 Layer	100A	74 (13)C
Clearfil 3 Layers	100A	84 (9)B
Without PBE	100A	92 (7)A

MQ, marginal quality, *PBE* proximal box elevation

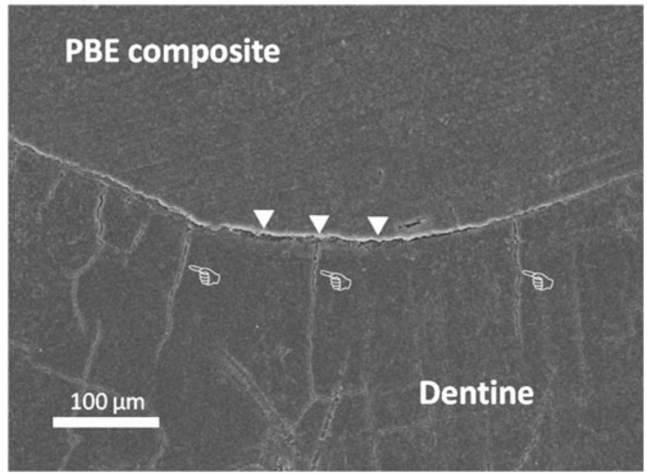

Fig. 6 Magnification of the box in Fig. 5. The margin of the PBE composite shows gap formation at the bottom of the proximal box in dentin (*arrowheads*) with some cracks (*indicators*) extending into dentin. This observation was seldom, but only made in specimens where PBE was carried out in one layer for relocation of the proximal margin

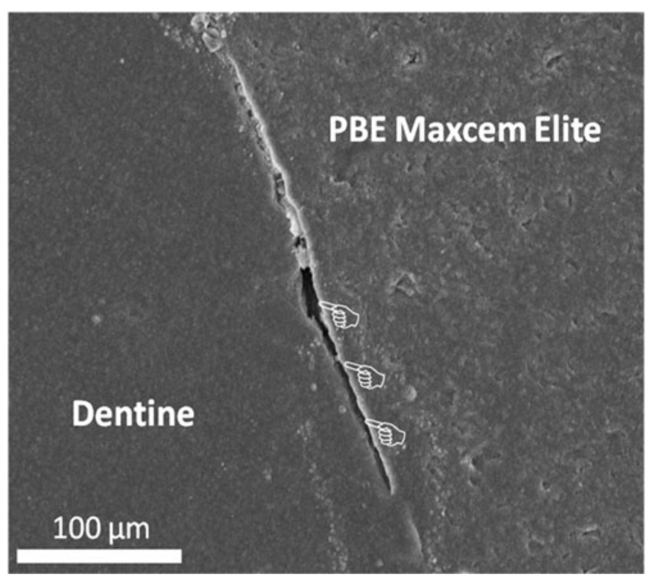

Fig. 7 Gap formation in a lateral aspect of PBE composite (Maxcem Elite)

Systematic reviews about ceramic inlays show acceptable annual failure rates [10, 12] with a remarkable deterioration of inlay margins over time [2, 5–7, 12, 13, 15–17]. Longitudinal loss of marginal performance is dependent on several cofactors like luting composite wear and adjacent structures being prone to fractures. Marginal quality evaluation was also the aim of the present study, however with another background being related to clinical circumstances. There is not so much of a difference between direct bonding of resin composite or indirect luting of ceramics regarding tooth hard tissue pretreatment, light curing, and related prerequisites [25]. However, moisture management in deep proximal boxes is difficult, especially when more adjacent cavities have to be treated, as often being the case in quadrant-wise restoration with inlays and onlays [29]. On first sight, it may be questionable why a so-called PBE technique should be of any advantage: The deep proximal box is the same, irrespectively of being bonded directly or indirectly. However, bonding a small portion of resin composite to the proximal box floor is a considerably faster procedure than luting one or even more indirect restorations in one quadrant [29]. This clearly means that the particular danger of contamination is much lower with the PBE technique, even when it is carried out without rubber dam using, e.g., an Automatrix. Furthermore, after PBE and finishing, rubber dam application is much easier during the luting session when the indirect restorations have been delivered by the dental technician. Another advantage of this technique would be that undermining caries in the proximal aspects would not have to result in extensive substance loss because this could be restored with resin composite first.

A recommendation of this technique is only possible when marginal integrity to tooth hard tissues is not affected in a sound in vitro approach. Therefore, it was the aim of the present study to investigate the influence of PBE on dentin margins and on resin–resin transition zones of milled CAD/CAM glass–ceramic inlays. The present study is not able to deliver an answer to the whole question dealing with deep proximal boxes and its special contamination aspect; however, it clarifies whether it is actually possible. Polymerization shrinkage of the applied resin composite during PBE should not be a major issue due to the limited amount of shrinking resin composite, but mechanical loading by the stiffer ceramic part, a differing modulus of elasticity, and a possibly weak transition zone between resin composite applied in the first session and freshly applied luting resin on sandblasted resin composite involve some questions about the durability of this procedure [30].

On the other hand, the present investigation is not able to determine the actual clinical advantage of the introduced technique because there was no simulation of contamination carried out. Nevertheless, it is reported, especially concerning luting of ceramic inlays, that it is a considerably technique sensitive and is presumably a more sensitive technique than the placement of direct resin composite restorations [28, 29]. In a previous clinical trial, it was shown that with the use of identical materials, the failure rate with different operators can be 0.6% vs. 12.2% [29]. This also means that any way of facilitating the clinical procedure of adhesive luting may be beneficial for general dental practice. Facing PBE, it may be considerably easier to bond one or two increments of resin composite to the proximal box floor compared with luting a complete inlay being permanently under contamination risk.

The selection of materials to be used in the present study was derived from earlier investigations as well as market issues. For the bonded resin composite, we chose a restorative resin composite with good biomechanical parameters such as flexural strength (Clearfil Majesty Posterior) [31] combined with an adhesive system being well suited for this kind of investigation (AdheSE) [32]. We chose one and three consecutive layers in order to estimate whether polymerization shrinkage affects the results even in these small amounts of resin composite. Self-adhesive resin cements were previously investigated not only as luting agents for indirect restorations [33] but also as core buildup materials [34]; therefore, three of them were also used in the present study because their application procedure is the simplest one, being primarily attractive for clinical situations prone to moisture contamination. On the other hand, direct application like a restorative material is almost unknown for this group of resin cements.

Another discussion point during the present experiments is the involved preparation mode. Performing PBE with an angled preparation design would have been easier to handle, but this preparation is not recommended when indirect restorations are applied [18]. Therefore, we chose a rounded half-circle preparation design of the proximal box, resulting in half-moon-shaped PBE resin composite areas. Although these particular areas of semi-direct restoration may be prone to biomechanical degradation under a thorough TML loading scenario, there was no negative influence found regarding marginal quality there.

The interpretation of the obtained results is clear: Under perfect clinical conditions, bonding glass–ceramics directly to dentin may still be the most effective way to counteract gap formation over time. However, although PBE/3 layers exhibited a significantly lower percentage of gap-free margins, the results for PBE/3 layers have been promising enough to allow this technique, primarily when clinical circumstances are considered, which have not been evaluated here. Moreover, the percentages of gap-free margins were much higher compared with direct techniques [25]. In previous times, it was repeatedly discussed whether resin composite inlays may act as better stress breakers than ceramic inlays resulting in less marginal breakdown [30]; however, this was neither confirmed with more actual finite element analyses nor with the present results, where even a 3-mm-thick potentially shock-absorbing layer leads to some dentin cracks (Figs. 5 and 6) [35]. Finally, both null hypotheses had to be rejected.

Conclusions

PBE can be a welcome aid for facilitating adhesive luting of ceramics to deep proximal areas. Three consecutive 1-mm layers as PBE show the best marginal quality to dentin. Self-adhesive resin cements are not recommendable for this indication.

Conflict of interest statement The authors have no conflict of interest.

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