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ORIGINAL ARTICLE

Influence of different cusp coverage methods for the extension of ceramic inlays on marginal integrity and enamel crack formation in vitro

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Abstract No information is available to date about cusp design of thin (1.0 mm) non-functional cusps and its influence upon (1) marginal integrity of ceramic inlays (CI) and partial ceramic crowns (PCC) and (2) crack formation of dental tissues. The aim of this in vitro study was to investigate the effect of cusp coverage of thin non-functional cusps on marginal integrity and enamel crack formation. CI and PCC preparations were performed on extracted human molars. Non-functional cusps were adjusted to 1.0-mm wall thickness and 1.0-mm wall thickness with horizontal reduction of about 2.0 mm. Ceramic restorations (Vita Mark II, Cerec3 System) were adhesively luted with Excite/Variolink II. The specimens were exposed to thermocycling and central mechanical loading. Marginal integrity was assessed by evaluating dye penetration after thermal cycling and mechanical loading. Enamel cracks were documented under a reflective-light microscope. The data were statistically analysed with the Mann–Whitney *U* test, the Fishers exact test (α=0.05) and the error rates method. PCC with horizontal reduction of non-functional cusps showed statistically significant less microleakage than PCC without such a cusp coverage. Preparation designs with horizontal reduction of non-functional cusps showed a tendency to less enamel crack formation than preparation designs without cusp coverage. Thin non-functional cusp walls of adhesively bonded restorations should be completely covered or reduced to avoid enamel cracks and marginal deficiency.

Keywords Ceramic inlays · Partial ceramic crowns · Cusp coverage · Marginal integrity · Enamel crack formation

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Introduction

Reasons for dental tissue loss are caries, abrasion or cracks [22] for which esthetic, tooth-coloured, biocompatible and tissue conservative restorations are asked for by the patients. Restorative procedures, like caries removal or cavity preparation, are accompanied by reduction of tooth stability, decrease of fracture resistance and increase of deflection of weakened cusps [6, 35]. Therefore, restorative materials have to replace dental tissues in form and function. Adhesively bonded ceramic restorations, e.g. ceramic inlays (CI) and partial ceramic crowns (PCC), are among cast gold restorations and amalgam fillings clinically accepted means to restoring extensively destroyed teeth [12, 39]. The term inlay is generally used to describe an intracoronal restoration without any inclusion of a cusp. However, to the knowledge of these authors, there is no generally accepted definition of the term PCC. For this study, we defined a PCC as an extended inlay preparation when at least one cusp has been included into the preparation [31].

The use of adhesive techniques opens the possibility of a more defect-oriented preparation preserving sound tooth structure, and therefore, accepted rules for the preparation design with a non-adhesive technique may not be valid for adhesive dentistry [38]. Furthermore, the adhesive technique is capable of reinforcing remaining dental hard tissues [5, 9] guiding masticatory forces from the restoration to a tooth/restoration entity [34]. Therefore, adhesion between tooth hard tissues and the ceramic would improve fracture resistance [37] and marginal adaptation [28]. However, marginal adaptation is still not perfect. Microleakage, resulting in hypersensitivity, recurrent caries, eventually pulpal pathoses, and fracture of ceramic and of remaining dental tissues are still clinical problems [17, 22].

Cracks of dental tissue are consequences of multiple stresses which may, as a result of thermal [23] or mechanical [6] processes, exceed the elastic limits of the tooth [32]. Those cracks may progress and result in tooth fracture which means, in a worst-case situation, the loss of the tooth [1, 15]. The resistance to fracture of a restored tooth may be influenced by many factors, e.g. the cavity size [26], the physical properties of the restoration material [7] and the luting system used [26]. In order to protect the weakened tooth, coverage of cusps with partial or full crowns is recommended [15, 27]. However, no information is available if coverage of thin (1.0 mm) non-functional cusps would improve the risk of tooth fracture or marginal imperfections. In practical terms, the decision has to be made if a planed inlay preparation has to be extended into a PCC preparation including the non-functional cusp or if a PCC preparation has to be further extended to cover the non-functional cusp.

Therefore, the purpose of this in vitro study was to evaluate the influence of cusp design on marginal integrity and enamel crack formation. It was hypothesised that this variable would affect marginal integrity of adhesively bonded ceramic restorations (CI and PCC) and enamel crack formation. Visible cracks in enamel have been used as early indicators of tooth fracture, and repeated stress during oral function was simulated by thermomechanical loading cycles.

Materials and methods

Sample preparation

Figure 1 summarises the procedures followed in the present study. Ninety-six extracted maxillary human molars, which had been stored in 0.5% chloramine solution after extraction, were cleaned, mounted in Pattern resin (GC Corporation, Tokyo) and stored in physiological saline solution until use. Diamond burs with an angle of 1.5° (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. 2):

– Initial ceramic inlay preparation (iCI):

Preparation of MOD cavities (width about 5.0 mm/depth about 4.0 mm); oral (functional) cusp about 2.5-mm wall thickness; vestibular (non-functional) cusp about 1.0-mm wall thickness.

– Extended ceramic inlay preparation (eCI):

Preparation of MOD cavities (width about 5.0 mm/depth about 4.0 mm); oral (functional) cusp about 2.5-mm wall thickness; vestibular (non-functional) cusp about 1.0-mm wall thickness and horizontally covered about 2.0 mm. According to the above given definition, eCI represents a partial crown preparation. However, for practical reasons, this preparation is coded as eCI.

– Initial partial ceramic crown preparation (iPCC):

Preparation of MOD cavities (width about 5.0 mm/depth about 4.0 mm); oral (functional) cusp about 2.5-mm wall thickness, with horizontal reduction of about 2.0 mm; vestibular (non-functional) cusp about 1.0-mm wall thickness.

– Extended partial ceramic crown preparation (ePCC):

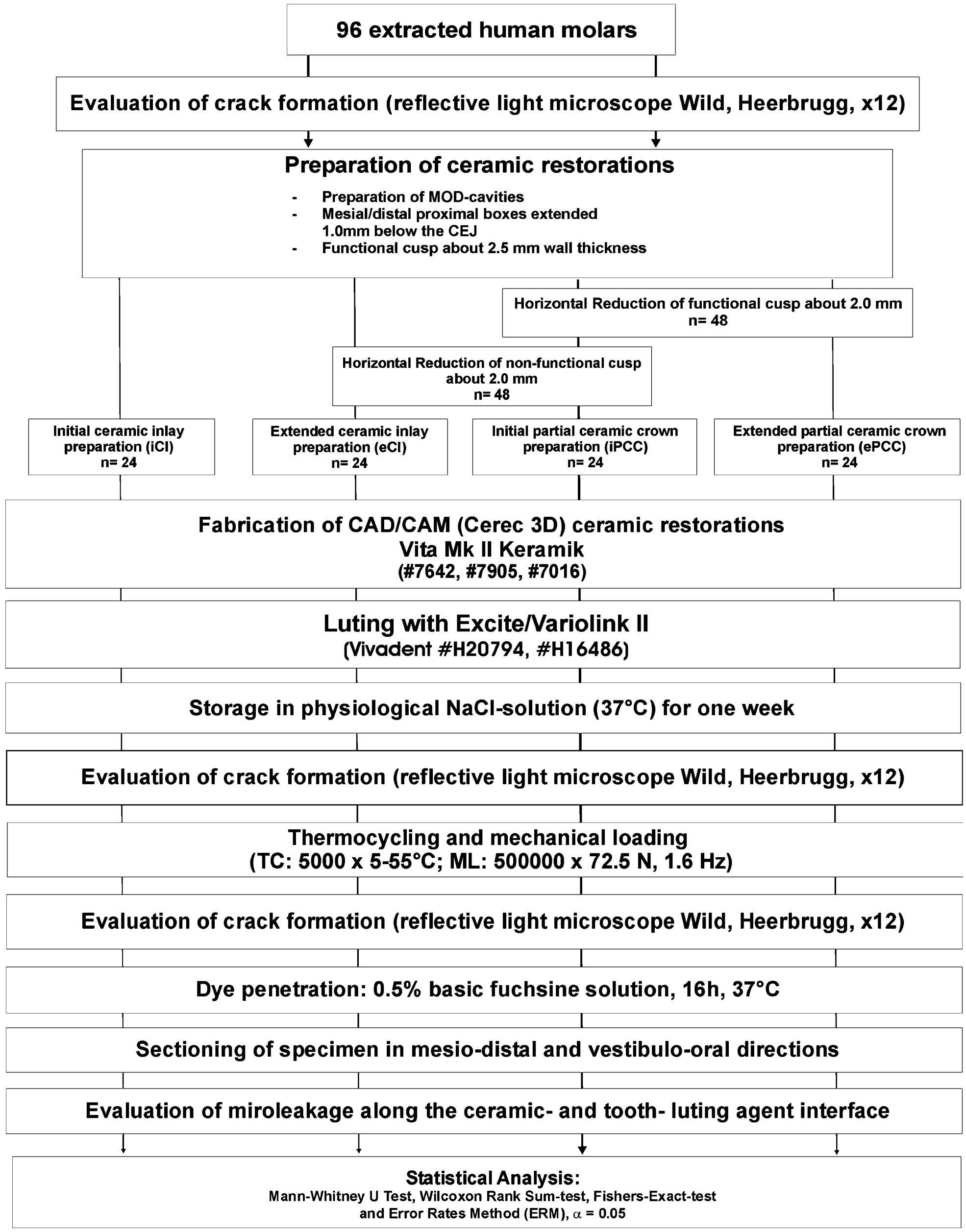
Preparation of MOD cavities (width about 5.0 mm/depth about 4.0 mm); oral (functional) cusp about 2.5-mm wall thickness, with horizontal reduction of about 2.0 mm; vestibular (non-functional) cusp about 1.0 mm wall thickness and horizontally covered about 2.0 mm.

Proximal margins were placed 1 mm below the CEJ within cementum/dentin, with a depth of about 1.5 mm. Internally, rounded line angles were prepared. The CAD/CAM method (Cerec 3 software version 1.0, Sirona, Bensheim, Germany) was used to construct and machine-mill the ceramic restorations from Mark II ceramic blocks (Vita, Bad Säckingen, Germany).

Following try-in and adjustment to the prepared cavities with Komet finishing diamonds (Brasseler, Lemgo, Germany) and sufficient water cooling, the ceramic restorations were inserted using Excite/Variolink II (Vivadent, Schaan, Liechtenstein), a dual-cured composite resin luting agent (12 specimens each per cavity design and cusp design). The restorative procedures were performed in a device simulating proximal contact to adjacent teeth to match the clinical situation as closely as possible. Luting material was applied to the cavity surfaces following adhesive conditioning of dental tissues and ceramic restoration surfaces. The luting procedure of Excite/Variolink II is summarised in Table 1.

Excess luting material was removed prior to curing. Following insertion procedures, finishing was performed with

Fig. 1 Flow chart: methods and materials



Komet finishing diamonds (Brasseler) and the restorations were polished with Sof-Lex flexible discs (3M, St. Paul, MN, USA). Before thermal cycling and mechanical loading (TCML), samples were stored in physiological saline solution at 37°C for 24 h. The samples were exposed to thermocycling (5,000×5 at 55°C and 30 s/cycle) and central mechanical loading (500,000×72.5 N at 1.6 Hz) simultaneously. Central mechanical loading was performed by means of a cyclic (1.6 Hz) increase in pressure (72.5 N) upon a stainless steel stop (diameter, 3.0 mm) representing the opposing cusp. The stainless steel stop was placed in the occlusal central fissure of the restoration (Fig. 3) and remained in contact during the loading cycles.

Determination of cusp wall thickness

Using a caliper, the actual tooth thicknesses of the vestibular cusp were evaluated before fabrication of the restoration and documented on three points (mesial, central and distal) at the bottom of the cavity for each specimen (Fig. 4).

Dye penetration

Following TCML, microleakage at oral (functional cusp), vestibular (non-functional cusp) and proximal locations for the ceramic- and tooth-luting agent (LA)

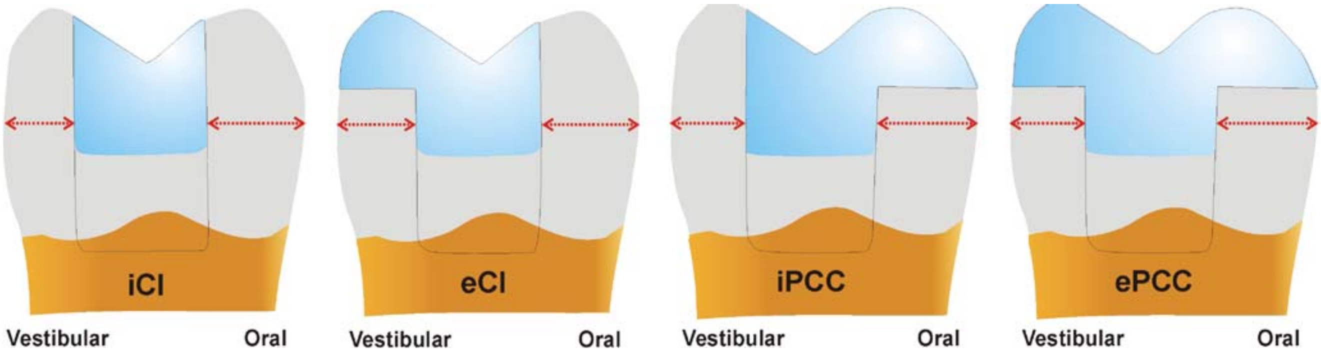


Fig. 2 Schematic drawing of the four different ceramic preparations (iCI, eCI, iPCC and ePCC) representing a midline cut in vestibulo-oral direction. *Dotted lines* indicate proximal, *boxes* below the CEJ and *red dotted arrows* indicate thickness of vestibular cusp wall (1.0 mm) and oral cusp wall (2.5 mm)

interfaces (enamel and dentin) was determined separately by means of dye penetration. Except for the areas within 1.0 mm from restoration margins, specimens were covered with nail varnish and placed in a 0.5% basic fuchsin solution for 16 h at 37°C. After dye penetration with fuchsin, the specimens were cleaned, mounted onto stubs with acrylic resin and consequently sectioned longitudinally in the mesio-distal and centrally in the vestibulo-oral directions into as many approximately 300-µm-thick sections as possible (4–8) using a rotating diamond saw (blade thickness 300 µm; Innenlochsäge Leitz 1600, Leitz) with sufficient water cooling. Each approximately 300-µm-thick section provided two sites for the evaluation of dye penetration. Digital images of the sections were used for measuring, and microleakage was recorded using an image analysing system (Optimas 6.1, Stemmer, Munich, Germany) at three locations: (1) the proximal cervical area (dentin-cementum), (2) vestibular area (enamel) and (3) oral area (enamel). Measurements were recorded separately for the tooth/LA and ceramic restoration/LA interfaces. The extent of dye penetration was expressed as a percentage of the entire length of the restoration wall (100% reference) as shown in Fig. 5. Four dye penetration measurements were recorded from each section, rendering 16–36 measurements per tooth (4×4–8 sections/tooth). The maximum value was selected for each tooth and used for further statistical evaluations.

Documentation of enamel cracks/fractures

Visible enamel cracks (Fig. 6) as discernable under a reflective light microscope (Wild Makroskop M420, Heerbrugg, Germany) at 12× magnification were evaluated and documented. Before preparation (BP), before TCML (BT) and after TCML (AT) oral and vestibular digital images of the specimen were taken.

Statistical analysis

Nonparametric statistical analysis was considered appropriate for analysing the data because of the lack of symmetry. For marginal integrity and enamel crack formation, medians and 25–75% percentiles for each experimental group (n=12) were determined for the different experimental conditions (cusp design and cavity design) and for the different locations (oral and vestibular cusp).

Marginal integrity All interfaces were considered separately. Statistical analysis was performed using the Mann–Whitney U and Wilcoxon rank sum tests (SPSS version 15.0; SPSS, Chicago, IL, USA) for pairwise comparisons among experimental groups.

Enamel crack formation Statistical analysis was performed using the Mann–Whitney U and Fishers exact test (SPSS version 15.0; SPSS).

Table 1 Luting material, cavity/ceramic conditioning and procedures of insertion

Luting material	Variolink II/VL High viscosity, composite luting agent (Vivadent)
Conditioning of ceramic	Ceramics Etch gel (Vita) 60 s, followed by rinsing with water Monobond S (Vivadent) applied and dried after 60 s
Conditioning of cavity	Total Etch (Vivadent) dentin 20 s, enamel 40 s, followed by water spray and gentle blow-drying Excite (Vivadent) application, after 20 s gentle blow drying, light curing for 20 s
Curing mode	Dual-curing (light application for 40 s from each aspect)

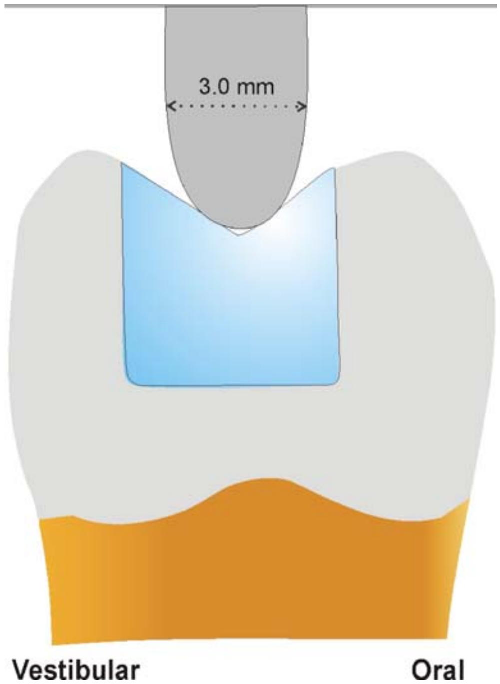


Fig. 3 Schematic drawing, representing a midline cut in vestibulo-oral direction, of the ceramic preparation and the stainless steal stop (diameter, 3.0 mm) placed in the occlusal central fissure of the restoration

For marginal integrity and enamel crack formation, the level of significance was set at α=0.05. For generally evaluating the influence of tested parameter, the level of significance was adjusted to $\alpha^*(k)=1-(1-\alpha)^{1/k}$ by application of the error rates method (k = number of paired tests to be considered).

Results

Dye penetration

The results of dye penetration for ceramic inlay preparations (iCI and eCI) are summarised in Fig. 7. Generally, dye penetration was statistically significantly higher for iCI (initial ceramic inlay preparation) with medians ranging from 18.8% to 88.3% than for eCI (extended ceramic inlay preparation) with medians ranging from 8.5% to 65.8%. This was supported by single pairwise comparisons, e.g. at the enamel/LA interface dye penetration of iCI (30.7%) was statistically significantly higher (p=0.001) than of eCI (9.3%) at the vestibular margin. For the parameter "location" (oral and vestibular cusp), error rates method (ERM) showed a statistically significant difference of dye penetration. In detail, single pairwise comparisons showed that dye penetration of vestibular cusps (30.7) was statistically significantly higher than dye penetration of oral cusps (22.5%) at the ceramic/LA interface of iCI. However, eCI revealed statistically significant less dye penetration of vestibular cusps (ceramic/LA, 8.5%; enamel/LA, 9.3%) than oral cusps (ceramic/LA, 17.3%; enamel/LA, 28.2%). For the parameter "interface" (ceramic–, enamel– and dentin–LA), there were significant differences (ERM) between interfaces. Ceramic– (8.5–60.5%) and enamel/LA interfaces (9.3–30.7%) revealed significantly less dye penetration than the dentin/LA interface (66.5–88.3%), which was also shown in single pairwise comparisons, e.g. dye penetration at the proximal margin of eCI was statistically significantly higher (p=0.005) at the dentin/LA interface (65.8%) than at the ceramic/LA interface (23.5%).

The results of dye penetration for partial ceramic crown preparations (iPCC and ePCC) are summarised in Fig. 7. Generally, dye penetration was statistically significantly higher for iPCC (initial partial ceramic crown preparation) with medians ranging from 20.1% to 100% than for ePCC with medians ranging from 5.5% to 84.1%. For the parameter "location" (oral and vestibular cusp), ERM showed no statistically significant difference of dye penetration. In detail, single pairwise comparisons revealed a statistically significant difference in two cases only [ceramic/luting agent interface, oral cusp (20.1%) vs vestibular cusp (37.3%) in iPCC and enamel/luting agent interface, oral cusp (10.5%) vs vestibular cusp (25.5%) in ePCC]. For the parameter "interface" (ceramic–, enamel– and dentin–LA), there was a significant difference (ERM) between the interfaces ceramic–, enamel– and dentin–LA. Ceramic– (5.5–54.8%) and enamel/LA interfaces (10.5–

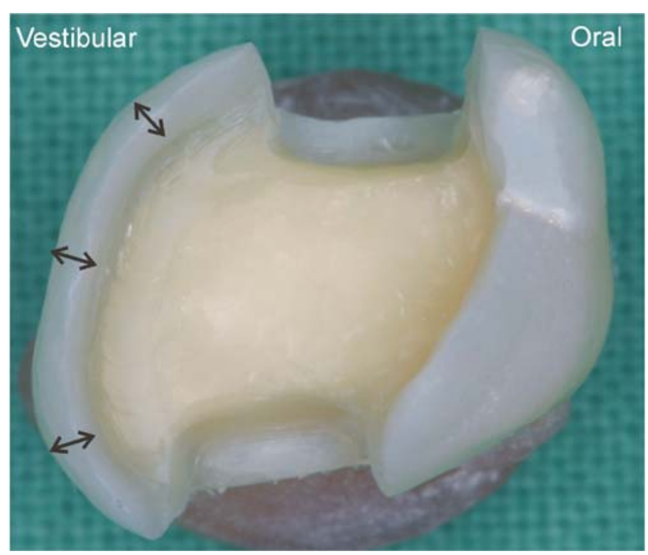


Fig. 4 Example of determination of cusp wall thickness; arrows indicate measuring distances for remaining cusp wall thickness of vestibular cusp

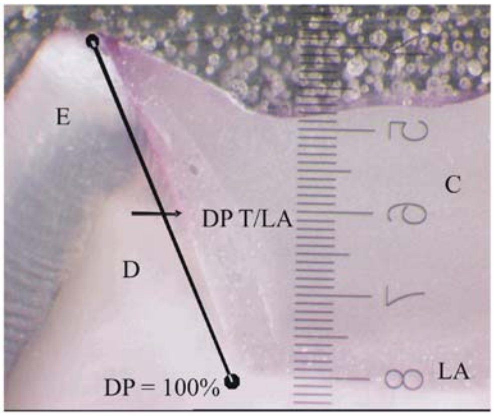


Fig. 5 Example of dye penetration (*DP*). *C* ceramic, *E* enamel, *T* tooth, *D* dentine, *LA* luting agent. *Arrow* indicates dye penetration at tooth/luting agent interface

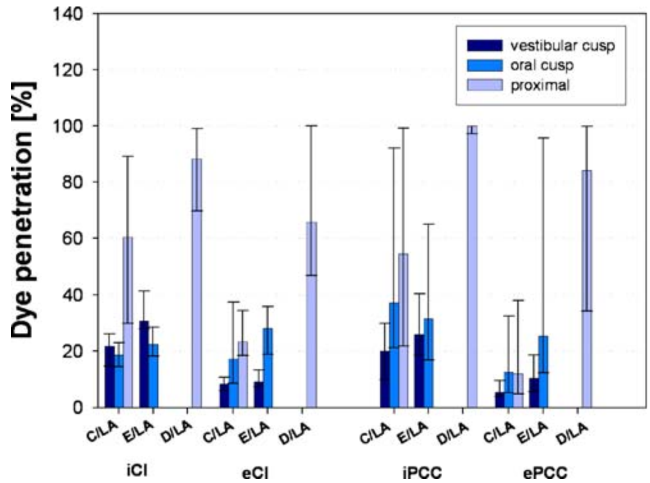


Fig. 7 Results of the dye penetration test after TCML for ceramic preparations (iCI, eCI, iPCC and ePCC) at the ceramic/luting agent (*C/LA*), enamel/luting egent (*E/LA*) and dentin/luting agent (*D/LA*) interfaces and vestibular (non-functional) and oral (functional) cusps (madian of maxima and 25–75% quartiles)

31.6%) revealed significantly less dye penetration than the dentin/LA interface (84.1–100%), which was supported by single pairwise comparisons, e.g. dye penetration at the proximal margin of ePCC was statistically significantly higher (p=0.002) at the dentin/LA interface (84.1%) than at the ceramic/LA interface (11.9%).

Comparisons between CI and PCC preparations showed, in general (ERM), no statistically significant influence upon dye penetration data. However, single pairwise comparisons revealed only in one case a statistically significant difference: eCI (18.8%) had oral statistically significant less dye penetration than ePCC (37.3%) at the ceramic/LA interface (p=0.007).

Enamel crack formation

Examples of visible enamel cracks before (BT) and after TCML (AT) are shown in Fig. 6. Crack lines are shown running from the top of the non-functional cusp towards the cemento-enamel junction. The results of enamel crack evaluation are shown in Table 2.

Enamel crack formation of CI For the parameter "time" (BT and AT), ERM showed statistically significant less enamel crack formation before than after TCML, which was supported by single pairwise comparisons, e.g. enamel crack formation at the vestibular cusp of iCI AT (15 enamel cracks) was statistically significantly higher (p=0.028) than BT (11 enamel cracks). For the parameter "cusp design" (iCI and eCI), ERM and single pairwise comparisons showed no statistically significant differences of enamel crack formation. However, eCI showed a tendency of less enamel crack formation than iCI before and after TCML. For the parameter "location" (oral and vestibular cusp), ERM revealed statistically significant less enamel crack formation at oral cusps than at vestibular cusps, which was also shown in single pairwise comparisons, e.g. enamel crack formation after TCML at the vestibular cusp of

Fig. 6 Example of enamel cracked tooth substance. *Arrows* indicate fracture lines. **a** Before TCML. **b** After TCML

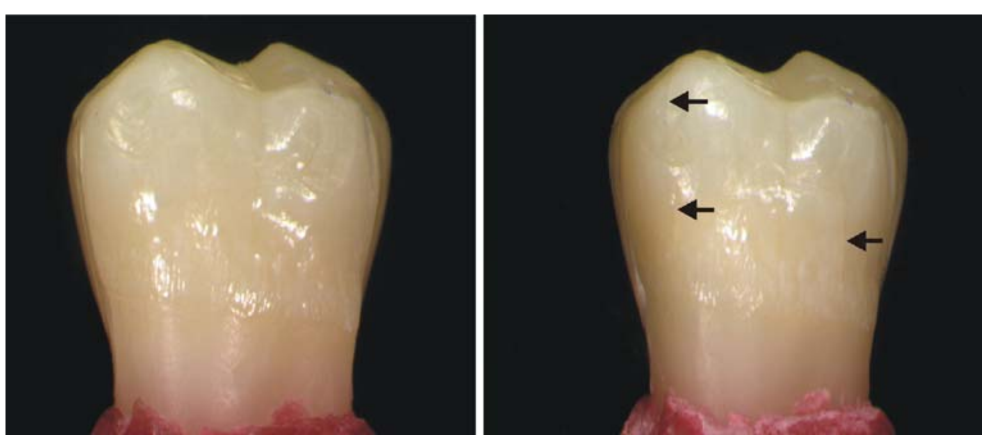


Table 2 Number of specimen enamel cracks for iCI (initial ceramic inlay preparation), eCI (extended ceramic inlay preparation), iPCC (initial partial ceramic crown prepartion), ePCC (extended partial ceramic crown preparation) before TCML (BT) and after TCML (AT), (median of maxima and 25–75% quartiles)

	CI preparation		PCC preparation	
	iCI	eCI	iPCC	ePCC
Vestibular cusp				
BT	11 (8/14)	10 (6/12)	12 (8.5/14)	11 (8/13.5)
AT	15 (10.5/16)	12 (8.5/15.5)	14 (10.5/18)	13 (10.5/16)
Oral cusp				
BT	8 (6/10)	8 (6/8)	14 (10/16)	8 (6/11.5)
AT	10 (8/10)	8 (8/12)	16 (10.5/20)	9 (6.5/13.5)

extended cusp designs (ten enamel cracks) was statistically significantly higher (p=0.000) than at the oral cusp (eight enamel cracks).

Enamel crack formation of PCC For the parameter "time" (BT and AT), ERM showed statistically significantly less enamel crack formation before than after TCML, which was also shown by single pairwise comparisons, e.g. enamel crack formation at the oral cusp of iPCC AT (16 enamel cracks) was statistically significantly higher (p=0.019) than BT (14 enamel cracks). Generally, enamel crack formation of iPCC was statistically significantly higher than enamel crack formation of ePCC, which was also shown in single pairwise comparisons, e.g. AT ePCC (nine enamel cracks) showed statistically significantly less enamel crack formation (p=0.002) at the oral cusp than iPCC (16 enamel cracks). For the parameter "location" (oral and vestibular cusp), ERM showed statistically significant differences of enamel crack formation. In detail, single pairwise comparisons revealed statistically significant less enamel crack formation at the oral cusps of ePCC (BT 8/AT 9 enamel cracks) than at the vestibular cusps (BT 11/AT 13 enamel cracks) of ePCC. However, vestibular cusps showed a tendency of less enamel crack formation than oral cusps of iPCC before and after TCML.

For the parameter "cavity design" (CI and PCC), ERM showed, in general, statistically significantly higher enamel crack formation for PCC (iPCC and ePCC), ranging from six to 20 enamel cracks, than for CI (iCI and eCI), ranging from six to 16 enamel cracks. This was supported by single pairwise comparisons, e.g. enamel crack formation of iPCC (16 enamel cracks) after TCML was statistically significantly higher (p= 0.000) than enamel crack formation of iCI (ten enamel cracks) at the oral cusp.

Discussion

Method

In the present study, the influence of four experimental conditions (non-functional cusp design, initial cavity design, location and time) on two endpoints (marginal integrity and enamel crack formation) was evaluated. Clinical studies of adhesively bonded ceramic restorations (ceramic inlays and partial ceramic crowns) proved clinical success and longevity [12, 20]. However, in vitro studies, i.e. regarding marginal integrity, seems to be necessary as screening process for evaluating and predicting clinical performance [14, 24]. Therefore, microleakage, defined as the passage of bacteria, fluids or molecules between a cavity wall and the restorative material applied to it [18], was measured by dye penetration, which is a commonly applied method to test the sealing of adhesive tooth-bonded restorations in vitro [25].

According to Krejci et al. [21], 120,000 in vitro loadings approximates 6 months of clinical use. Therefore, the present study should simulate approximately 2–2.5 years of clinical use. Dye penetration after TCML was assessed in order to better simulate the in vivo situations. A definite relationship, however, between in vitro dye penetration and results from clinical (in vivo) testing still remains to be established, with problems probably arising from evaluation deficiencies for both the in vitro and the in vivo methods. However, in the present study, dye penetration was used to compare the different cusp and cavity designs.

In the present study, the appearance of visible cracks of enamel has been used as an early indicator for tooth fractures, which seems to be the result of the accumulation of repeated stress during oral function. Lloyd et al. [23] differentiated between long and short enamel cracks, with short cracks, beginning in the gingival region because of small enamel thickness. These small cracks may not result in tooth fracture [3], but growth of these cracks can be detrimental as they may serve as sites for demineralisation [40] and further mechanical degradation [3]. In the current study, we did not distinguish between long and short cracks because for practical reasons, it was difficult to clearly distinguish between both.

So far, fracture resistance of tooth substance has been mainly tested by basic laboratory methods where increasing load is applied on the indented surface until fracture [16, 35]. These methods use the acute single loading failure as the test procedure, but tooth fracture rather seems to be the result of the accumulation of repeated stress during oral function [35]. TCML was used as a commonly applied method [4, 29, 30] to simulate clinical situations, such as masticatory forces under wet conditions. According to Arola and Huang [2], TCML contributes to cusp fracture and/or tooth cracking.

Diagnosis of cracks may be difficult, and therefore, staining the crack, applying transillumination or using an operating microscope has been proposed to solve this problem [8]. In the present study, a reflective light microscope at 12× magnification was used to visualise and evaluate the enamel crack formation, and we were able to detect differences between the experimental groups. To establish comparability throughout the study, all specimens were evaluated by one person.

Marginal integrity

Cusp design had, in general, a statistically significant influence on marginal integrity. iCI and iPCC (1.0-mm wall thickness) showed more marginal deterioration compared to eCI and ePCC (1.0-mm wall thickness with horizontal reduction). To the best of our knowledge, this is the first experimental indication in a clinical simulation experiment that for all-ceramic restorations, coverage of thin (1.0 mm) remaining cusp wall thickness is necessary to reduce marginal deterioration. It may be speculated that thin (1.0 mm) remaining cusp wall thickness resulted in indirect stressing of tooth structure and reduced marginal integrity of the adhesively bonded ceramic restorations.

Proximal restoration margins within dentin revealed more marginal deterioration compared to enamel– and ceramic–LA interfaces. The data are in accordance with results reported in the literature where cervical restoration margins within dentin revealed significantly lower marginal deterioration than within enamel [10, 11, 33].

Marginal integrity was shown to be, in general, independent of cavity design (CI and PCC). The data are in accordance with Kramer et al. [19] for clinical behaviour of inlay restorations and onlay restorations Those authors reported that neither the absence of enamel margins nor cuspal replacement significantly affected the quality of the restorations. However, this is in contrast to Fonseca et al. [13] who tested different cavity preparation designs of laboratory-processed resin composite restored teeth. The effect of occlusal width extension on marginal accuracy of indirect composite resin restorations showed lower values of gaps width in wide preparations, but the authors concluded that in a clinical situation, this would mean greater removal of sound tooth structure. Therefore, less aggressive preparations combined with other restorative procedures seem to be more feasible.

Enamel crack formation

Parallel to the data for marginal integrity, better results (i.e. less enamel crack formation) were observed in eCI and ePCC compared to iCI and iPCC. At first glance, there is no direct link between marginal integrity and enamel crack formation. It may be speculated that the different geometry (coverage/no coverage) influences marginal integrity and enamel crack formation independently. To the best of our knowledge, this is the first experimental indication in a clinical simulation experiment that for all-ceramic restorations, coverage of thin (1.0 mm) remaining cusp wall thickness is necessary to prevent enamel crack formation.

The present data also show that the cusp-stabilising effect of adhesive restorations [5, 9] seems to be limited because the number of enamel cracks with a minimal wall thickness (1.0 mm) without cusp coverage is increasing and, thus, the risk of tooth fractures. This is in contrast to Stappert et al. [36] who showed that ceramic coverage of compromised cusps did not demonstrate an increase of fracture resistance after fatigue compared to less invasive partial coverage restorations. In addition, Habekost et al. [16] showed that inlay restorations exhibited superior resistance to fracture compared to the other cavity designs (restoration with only palatal cuspal coverage and onlay with palatal and buccal cuspal coverage). However, in contrast to our study, in these two studies, the restored teeth were loaded until fracture (acute failure). The observed differences in the results may indicate that repeated subcritical loading as done in our study and which represents the actual load for restoration results in a different damage pattern than acute loading. The generally larger number of cracks observed for PCC compared to CI may be attributed to the more extensive preparation for the PCC.

Conclusions

Within the limitations of the present study, it can be concluded that thin (1.0 mm) non-functional cusp walls of adhesively bonded ceramic restorations should be covered to reduce the risk of enamel crack formation, which—in the long run—may avoid tooth fracture. Furthermore, coverage of thin non-functional cusp walls may reduce marginal deficiency at the ceramic– and tooth/LA interfaces.

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Conflict of interest The authors declare that they have no conflict of interest.

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