PARTIAL CERAMIC CROWNS. ESTHETIC AND TISSUE CONSERVATIVE RESTORATIONS – PART I: POSTERIOR TEETH

Gottfried Schmalz[1,2a*], Marianne Federlin[1b]

[1]Department of Operative Dentistry and Periodontology, Medicine Faculty, University Hospital Regensburg, D-93052 Regensburg, Germany
[2]School of Dental Medicine (ZMK Bern), University of Bern, CH-3010 Bern, Switzerland

[a]DMD, PhD, Professor, Dr. h.c.
[b]DMD, PhD, Professor

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ABSTRACT

Background: Partial ceramic crowns (PCCs) are more tooth conservative and potentially less stressful for the periodontium than full coverage crowns and meet the esthetic demands of patients.
Objective: evidence shall be provided, if PCCs are a reliable treatment option, and under which conditions.
Data sources: this review is based on own published data and experiences and on a review of the literature.
Results: Longevity of PCCs is in the range of partial crowns from gold alloys. Failures due to chip fractures, bulk fractures, or debonding can be avoided/reduced by proper technique. Most clinical experience exists with leucite reinforced silicate or lithium disilicate ceramics, either pressed or CAD/CAM processed. Tooth preparation must respect the need for sufficient ceramic thickness of at least 1.5 mm. Residual buccal or oral cusps of less than 2 mm thickness should be included in the preparation. Cavity preparation should be defect oriented with few parallel walls as guidance for placement. Dual curing luting composites together with etch and rinse (E&R) adhesives are standard. Self-adhesive materials can be used but are sensitive to tooth desiccation before luting. Clinical experience with new universal adhesives is limited, but available results are promising. Light curing should be performed by applying 32 J/cm^2 from oral, buccal and occlusal aspects (silicate based ceramics).
Conclusions: PCCs are a reliable treatment option for extended defects in posterior teeth. Special guidelines must be followed including sufficient ceramic thickness and proper adhesive technique to avoid failures.
Keywords: partial crowns, ceramic, light curing, luting composite.

1. Introduction

Modern dentistry offers a large variety of different treatment modalities for large cavities in posterior teeth which need replacement of one or more cusps. Direct restorative techniques employing amalgam as well as resin-based composites in combination with the adhesive technique are increasingly being used in such cases on the one hand. However, on the other hand, the insertion of full crowns is still a well-recognized and widely-used procedure. Such full crowns are mainly fabricated either from gold alloys, non-precious metals, ceramics or combinations (metal ceramic crowns). Beside this, so-called partial crowns made from gold alloys have a long tradition as tooth tissue conservative alternative to full crowns, which also imply less stress on the adjacent periodontium.

Obviously, the esthetic properties of metallic partial crowns are not meeting our patients' high expectations in terms of virtually invisible (i.e. tooth colored) restorations. Therefore, it has been proposed to adopt the tissue conservative technique of metallic partial crowns to tooth colored materials, especially to ceramics, encouraging the fabrication of partial ceramic crowns (PCCs). PCCs would allow for a defect-oriented preparation and a tooth-colored restoration.

Fig. 1 shows a clinical case, where this technique was applied in a posterior tooth. Undoubtedly, the esthetics are pleasing. The question however is, if this is a reliable method, which can be recommended to the patients and what features have to be addressed in order to end up with a predictable treatment outcome. Here we describe our own experiences covering the recent 20 years and data from the literature adressing partial ceramic crowns in posterior teeth. In part II we concentrate on laminate veneers.

2. Definitions

A partial crown is defined as a restoration with partial

***Corresponding author:**
Professor Dr. Dr. h.c.Gottfried Schmalz, DDS, PhD, Department of Operative Dentistry and Periodontology, University Hospital Regensburg, Franz-Josef-Strauss Allee 11, D-93052 Regensburg, Germany, Tel: +49-941-944-4980, Fax: +49-941-944-4981, e-mail: Gottfried.schmalz@ukr.de

Baseline (1994): Preparation Restoration Restoration (2008): 14 years in situ

Figure 1. Restoration of a molar with an insufficient amalgam restoration using a partial ceramic crown: a tooth conservative and esthetically pleasing restoration.

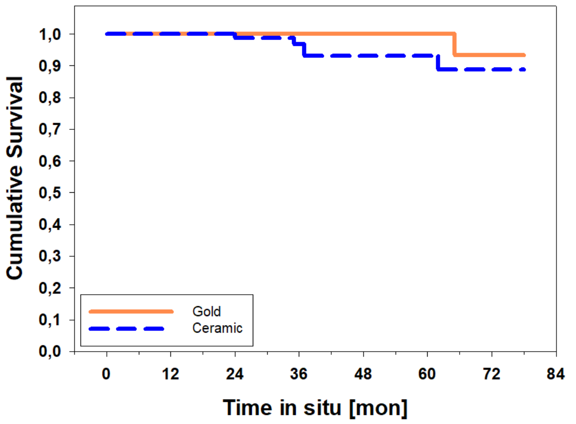

Figure 2. Survival rate (Kaplan Meier) of partial crowns from Vita Mark II feldspatic ceramic and from gold alloy after up to 5.5 years: no statistically significant difference (Federlin M, et al. Controlled, prospective clinical split-mouth study of cast gold vs. ceramic partial crowns: 5.5 year results. Am J Dent. 2010;23(3):161-167).

replacement of the clinical crown including part of the occlusal surface (at least one cusp) in posterior teeth. Other terms frequently used are "onlays", or "overlays". For the sake of simplicity, in this review we use the terms partial ceramic crowns, onlays and overlays synonymously. The term "table tops" is used for the singular replacement of occlusal surfaces; e.g. in teeth with extensive wear.[1] This method is not covered in this article.

3. Longevity

Ample experience mainly from retrospective studies exists with inlays from gold alloys with an excellent longevity of over 90% in situ after up to or longer than 10 years[2,3] and with metallic partial crowns (e.g. 76% to more than 86% survival) after up to 10 years.[4,5] Also, for ceramic inlays, available data show up to 98 % success after up to 8 years[6,7] coming close to gold alloy inlays. Less favorable results were reported for inlays from castable ceramics (76 % after 6 years), a material, which is no longer available.[8]
In analogy to the results for ceramic inlays, partial ceramic crowns fabricated from a castable glass ceramic (Dicor) only showed a 56% success rate of the restorations after 7 years in a retrospective study.[6] However, using a leucite reinforced glass ceramic (Empress), 81% of the restorations were still in situ after 7 years.[9] In a prospective, split mouth study comparing the longevity of gold alloy partial crowns to that of ceramic partial crowns (leucite reinforced glass ceramic), 89% of the initially inserted PCCs were still in situ after 5.5 years (Fig. 2) being statistically not different from gold alloy partial crowns.[10]
Another prospective clinical split-mouth study compared PCCs made from leucite reinforced ceramic (CAD/CAM) with lithium disilicate ceramic (pressed) PCCs in vital first or second molars. The 7-year Kaplan-Meier survival rate was 100% for pressed PCCs and 97% for CAD/ CAM PCCs.[11] These results are in the same order of magnitude as for all ceramic full coverage crowns, e.g. for leucite reinforced glass-ceramic crowns: (93.7%)[12] or 94.8% of the crowns (and more) in situ after up to 10 years (Lithium-disilicate).[13,14]
In conclusion, we estimate that ceramic partial crowns have the potential for being a reliable treatment method with survival rates which are in the same order of magnitude as those for full metal crowns.

4. Failure analysis

Chip fractures were observed (Fig. 3), probably due to incorrect occlusal adjustment or bruxism. This stresses the importance of correct occlusal adjustment. Furthermore, bulk fractures of the ceramic partial crowns were seen especially when the ceramic thickness was insufficient (less than 1.5 mm) (Fig. 4). This stresses the importance of a correct tooth preparation, respecting the material characteristics of the ceramic used, like a minimal thickness of 1.5 mm (see also preparation below).[11,15]
Fractures may also occur due to a so-called "crack propagation" (Fig. 5); i.e. that small cracks increase over time due to mechanical stress, fatigue and eventually hydrolysis. Crack propagation may start from flaws at the base of the restoration (e.g. during fabrication process) or from flaws at the surface of the restoration (e.g. wear or unfinished surface following adjustments). A further reason for initiating small cracks is the incorrect (= heat producing) grinding and polishing during occlusal and approximal adjustment of the ceramics.[16]
Discoloration and wear of the luting material are also reported. Here, a small primary marginal gap between the ceramic restoration and the cavity wall, which has to be filled with the luting material, is beneficial. Furthermore, the correct choice and use of the luting material seems to be an important factor. By e.g. repolishing discolorations can be reduced to some extent. In this article, we describe techniques, which shall help to keep failures with PCCs at a minimum.

Figure 3. Chipping fracture of a partial ceramic crown.

Figure 4. Bulk fracture of a partial ceramic crown due to too little thickness of the ceramic.

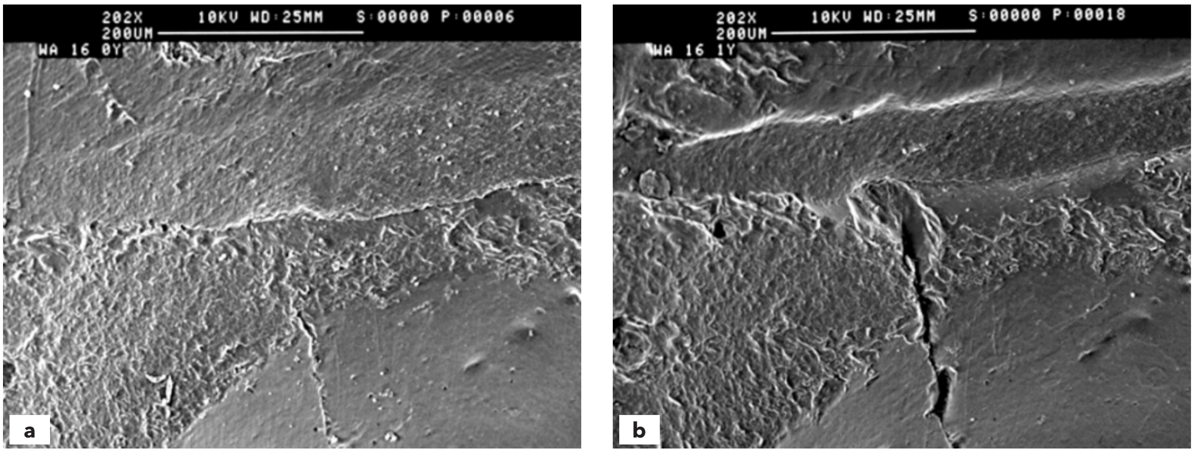

Figure 5. Scanning electron picture of a crack propagation in a ceramic restoration: (a) at baseliine (b) after 4 years (Friedl KH, et al. Clinical and quantitative marginal analysis of feldspathic ceramic inlays at 4 years. Clin Oral Investig. 1997;1(4):163-168).

5. Which Ceramic?

A large variety of different ceramic materials for partial crowns are available. They can be classified according to their composition or to the way they are processed. A survey of ceramics based on the composition is presented in Fig. 6.

Material

Ceramic materials differ e.g. in their mechanical and esthetic properties. In comparison to metals/alloys, which undergo some plastic deformation after the application of load, ceramics are considered to be brittle with no/very little plastic deformation, which can absorb energy.[17,18] The strength of ceramics is usually assessed by means of classic flexural strength tests using bar- or disk-shaped specimens[19] reflecting sudden application of a heavy load. Additionally, fracture toughness is a measure of resistance to crack propagation.[19] Esthetic properties are mainly related to the translucency of ceramics,[18] the higher the translucency, the better the esthetics.

Dental ceramics materials can be subdivided into three groups:[18]

a. primarily glass containing (feldspatic) ceramics based on silicate (also termed silica, SiO_2)

b. leucite reinforced silicate ceramics, lithium disilicate ceramics, or zirconium oxide reinforced lithiumsilicate ceramics

c. Mainly crystalline oxide ceramics (aluminum oxide, zirconium oxide) (Table 1).

Feltspatic ceramics in general show very good esthetics, but comparatively low mechanical strength (Table 1). Therefore, these materials were either reinforced with leucite, or are based on lithium disilicate; additionally, zirconium oxide reinforced lithiumsilicate ceramics have been introduced. All silicate based ceramic materials need to be adhesively luted to the tooth substrate. Examples for materials with long clinical experiences are leucite reinforced silicate ceramic (e.g. Empress I, formerly named Empress) or lithium disilicate ceramic, which contains 70% needlelike Lithium disilicate crystals (3-6 µm long) in a glass matrix (IPS e.max Press for labside fabrication and IPS.max CAD for chairside, CAD/CAM fabrication). This material shows better mechanical properties than leucite reinforced ceramics but still adhesive luting is recommended. At least 1.5 mm thickness is recommended for restorations made from these ceramics (see also preparation).[18] Recently, zircon oxide reinforced lithium silicate ceramics containing 10 wt.% 0,5 µm

Table 1. Flexural strength and Fracture toughness of different ceramics; modified according to (Raigrodski AJ. Contemporary materials and technologies for all-ceramic fixed partial dentures: a review of the literature. J Prosthet Dent. 2004;92(6):557-562; Aurelio IL, et al. Extended glaze firing improves flexural strength of a glass ceramic. Dent Mater. 2015;31(12):e316-324; Drummond JL, et al. Fracture surface examination of dental ceramics using fractal analysis. Dent Mater. 2005;21(6):586-589).

Material	Flexural strength (MPa)	Fracture toughness KIC(MPa/m1/2)
Leucite reinforced	140-210	1.2-2.0
Lithium disilicate reinforced	300-400	2.8-3.5
Zirconia oxide (Y-TZP)	900-1200	9-10

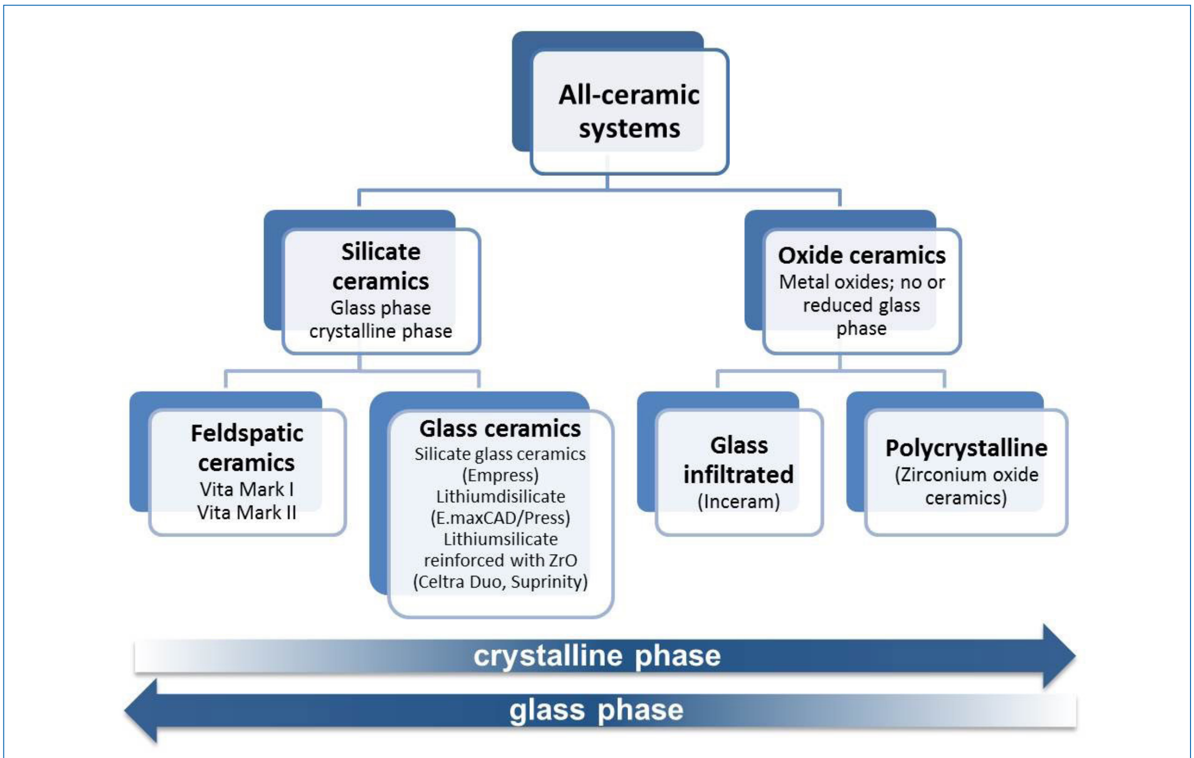

Figure 6. Overview of dental ceramic materials.

ZrO_2 have been introduced as an alternative material for the fabrication of single unit ceramic restorations which have to be adhesively luted. Restorations can be fabricated either labside (Celtra, Celtra Press; Suprinity) or CAD/CAM chairside (Celtra Duo, with an optional sintering step). Zircon oxide reinforced lithium silicate ceramics exhibit good mechanical properties and are translucent. Little clinical experience, however, exists with this ceramic for PCCs yet, and therefore this class of ceramics is not further covered in this review.

Oxide ceramics show low translucency compared to silicate ceramics but much better mechanical properties, which is due to the high amount of crystals.[18] Both, adhesive and conventional luting is possible. Adhesive luting, however, needs special ceramic pretreatment.[18] Today, monolithic restorations can be fabricated from zircon dioxide ceramics, but the range of indication rather covers crowns, bridges and more complex restorations than partial ceramic crowns. Therefore, this class of ceramics will not be addressed in this review.

Recently, materials named "Hybrid ceramics" have been marketed. These are, however, basically resin-based composites and/or contain methacrylate monomers. Therefore, the term "hybrid ceramic" may be misleading. These materials are industrially manufactured and must be processed by CAD/CAM techniques. They include heavily particle filled resins (i.e. resin based composites) cured at high temperature/pressure (e.g. Lava Ultimate, 3M or Cerasmart, GC) or a resin interpenetrating network (IPN) in a porous ceramic structure (e.g. Enamic, Vita). The latter material contains 86 wt.% feldspatic ceramic, which is infiltrated with resins (14 wt.% polymers). It has a strength of 144,4 MPa,[20] like glass ceramic (Mark II) but lower than lithium disilicate and a lower elastic modulus compared to other ceramics ranging between enamel and dentin.[20] Adhesive luting is required for these materials. Other similar materials are being marketed. For this group of materials little clinical experience for PCCs exists for the time being.

Processing methods

Initially, (feldspatic) ceramics were processed by sintering or - in the 80s of last century - by casting (e.g. Dicor). The method was based on impression taking and further processing in a dental laboratory. However, mechanical properties of the resulting restorations were limited and especially for the castable ceramics failure rates for partial crowns were high.[6]

Pressing of ceramic was introduced using leucite reinforced ceramic (Empress I) in the 90s of last century with better clinical results. Further improvements were achieved using lithium disilicate (IPS e.maxPress) ceramics for the pressing process. However, again the restorations were fabricated in a dental laboratory after impression taking.

A basic change in the processing of ceramics occurred with the introduction of CAD/CAM techniques, which employed an optical impression (or scan), and the restorations were constructed by means of a computer program (CAD – Computer Aided Design). The restorations were then fabricated by 3-D-milling (CAM – Computer Aided Manufacturing) of an industrially prefabricated bloc. Restorations could be fabricated chairside, but also in a dental laboratory. This method has gained more and more importance recently.

Which ceramic to select?

Selection of the suitable ceramic materials/ceramic processing methods should be based on scientific data. Here, results from clinical studies over at least 3-5 years are of special relevance. For leucite enhanced glass ceramics and for lithium-disilicate ceramics such studies are available (see above: longevity). Regarding the aspect of processing of ceramics, broad and positive clinical experience exists with pressing techniques and with CAD/CAM. If the restorations are produced in a dental laboratory, an experienced technician and a close communication between dentist and technician are essential. In our clinic, we have extensive and positive experience over more than 20 years with leucite reinforced and lithium disilicate ceramics using the pressing technique or the CAD/CAM approach.

Fabrication of a ceramic partial crown

In the following series of figures, the fabrication of a lithium disilicate CAD/CAM partial crown is shown (Fig. 7a to 7f). After the optical "impression" the partial crown is constructed with the help of a computer program. In our clinic we are using the CEREC 3 system (Cerec Bluecam and Cerec Omnicam, Software Version SW 4.4.4.139706). Then, a suitable ceramic bloc is selected matching best in tooth color. Milling is performed on the blue bloc with partially crystallized 40% plate-like lithium-metasilicate crystals (0.2-1.0 µm) in a glass matrix (ca. 130–150 MPa). After try in, the restoration has to be heat treated to receive its final color, individualization,

Table 2. Results from an in vitro study comparing the fracture rate of ceramic (Vita Mark II) with 0.5 to 1 and 1.5 to 2 mm thickness; modified according to (Federlin M, et al. Partial ceramic crowns: influence of ceramic thickness, preparation design and luting material on fracture resistance and marginal integrity in vitro. Oper Dent. 2007;32(3):251-260).

	Ceramic Thickness	Fractures (n)
Rely X Unicem	Group 1 (0.5-1 mm)	7
	Group 2 (0.5-1 mm)	1
Variolink II	Group 1 (0.5-1 mm)	8
	Group 2 (0.5-1 mm)	1

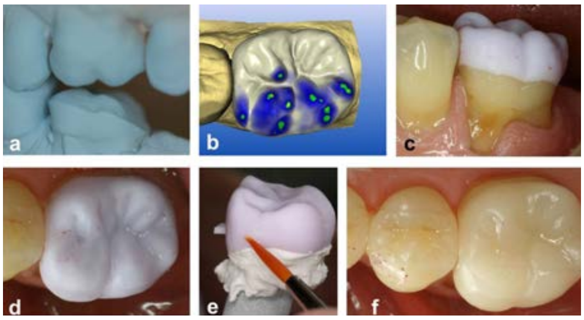

Figure 7. Fabrication of a lithium disilicate partial crown using a CAD/CAM approach: (a) preparation, (b) CAD of the restoration, (c) try-in of the metasilicate restoration, (d) occlusal adjustment, (e) preparation for final firing, (f) luted partial crown.

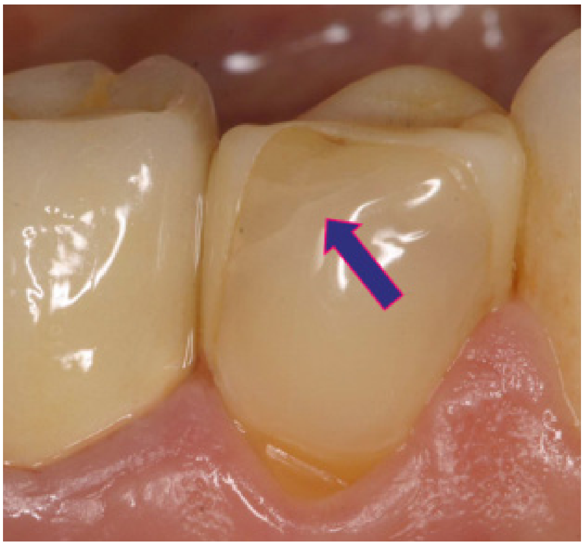

Figure 8. Crack formations on the buccal wall of a tooth with a PCC without coverage of the functional, buccal cusp.

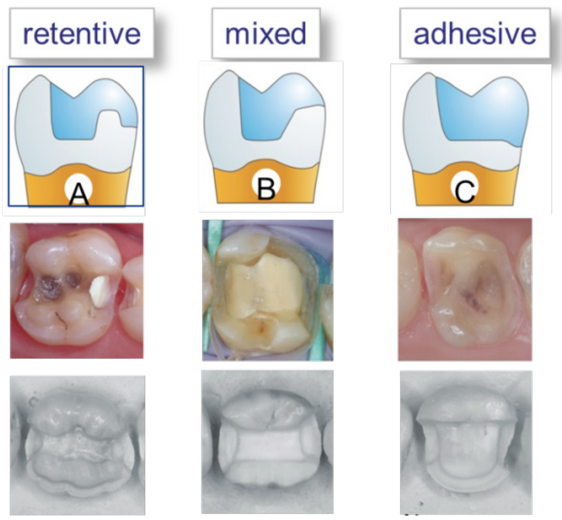

Figure 9. Retentive, semi-retentive and non-retentive cavity designs for the in vitro study on marginal quality (Federlin M, et al. Partial ceramic crowns. Influence of preparation design and luting material on margin integrity--a scanning electron microscopic study. Clin Oral Investig. 2005;9(1):8-17).

a b c d

Figure 10. Preparation and polishing instruments for ceramic partial crowns: (a) cylindrical diamond burs (course and fine grit) with rounded edges, (b) conical instruments with rounded edges and a stop at the frontal part, in order to keep the cavity depth, (c) ultrasound preparations tips for finishing approximal boxes, (d) silicone or rubber based instrument for polishing ceramic surfaces after occlusal/approximal adjustments.

glaze and strength. In this step the lithium-metasilicate is converted to lithium disilicate, then having its final mechanical strength (360-400 MPa).

6. Which Preparation?

Problems of ceramic fractures related to its mechanical properties and the resulting failures have been outlined above. Rules for a suitable preparation must first of all take care of these material properties.

Ceramic thickness

The necessary thickness of the ceramic to avoid crack propagation or fracture on loading was investigated in an in vitro study simulating repeated subcritical loading and thermocycling.[21] PCCs (Vita Mark II, Cerec3 System) were fabricated with 0.5-1.0 mm and 1.5-2.0 mm ceramic thickness. PCCs were adhesively luted to the cavities with either Excite/Variolink II or RelyX Unicem. After thermo-mechanical loading 15 PCCs of group 1 (0.5-1.0 mm) and two PCCs of group 2 (1.5-2.0 mm) fractured. The difference was statistically significant. Although the test material (Vita Mark II) is a feldspatic glass ceramic with less strength than the current lithium disilicate or zircon oxide reinforced lithium silicate ceramics, we still recommend – being on the safe side – a minimum thickness of the ceramic of 1.5 to 2.0 mm (Table 2).

Inlay or Partial Crown

The decision, whether the preparation design should include the cusps (partial crown) or not (inlay), should be based on both, the size of the defect and the luting technique (adhesive/non-adhesive). Tooth fractures or crack formation as a possible precursor of fractures may occur if the remaining tooth structure is too weak (Fig. 8). For non-adhesively luted/placed dental restorations, the generally accepted rule was that if the occlusal cavity is larger than 1/3 of the oral vestibular distance of the tooth, the cusp had to be covered. However, information concerning adhesively luted ceramic restorations was lacking.

Therefore, in an in vitro study,[22] cavities were prepared for PCCs with the non-functional cusps not covered and adjusted to wall thicknesses of 1.0 mm and 2.0 mm. Ceramic restorations were fabricated and adhesively luted to the cavities with Excite/Variolink II. After thermo-mechanical loading the specimens with 1.0 mm of remaining wall thickness revealed statistically significant more cracks after TCML than the group with 2.0 mm of remaining cusp wall thickness. (Table 3). In another study,[23] restorations with 1 mm thin cuspal wall with and without coverage were compared using the same method as described above. Horizontal reduction of thin non-functional cusp walls showed a tendency of less enamel crack formation and better marginal sealing than thin (= 1 mm) non-functional cusp walls without coverage.

Although the clinical relevance of cracks for the functioning of teeth was questioned, it was shown that enamel cracks may progress toward a complete loss of the whole tooth wall, which would require a new restoration or even tooth extraction.[24,25]

From these studies it can be concluded that – to be on the safe side – a remaining cusp wall thickness of less than 2 mm should be protected by coverage with an at least 1.5 to 2 mm thick ceramic layer to avoid/reduce enamel cracks and marginal deficiencies.

Preparation design

Traditionally, the preparation design for partial crowns using metal alloys was "retentive" with artificially created rather parallel box walls in order to support the retention of the metal restoration by friction. However, ceramic partial crowns are adhesively luted, by which bond strength between restoration and tooth is significantly improved. Therefore, the question was, if PCCs still require a retentive preparation. In an in vitro study, the

Table 3. In vitro increase of crack formation in enamel for 1 mm and 2 mm residual dental wall thicknesses after luting and after thermo-mechanical loading; numbers of samples (teeth); modified according to (Krifka S, et al. Ceramic inlays and partial ceramic crowns: influence of remaining cusp wall thickness on the marginal integrity and enamel crack formation in vitro. Oper Dent. 2009;34(1):32-42).

	BL vs. luting		Thermo/mech loading vs. BL		Natural teeth
	1 mm	2mm	1 mm	2 mm	
No changes	6	8	0	5	11
Increase of cracks	7	4	13	7	1

Critical thickness of ceramic = 2 mm

Figure 11. Different preparation designs, from a prospective clinical study.

influence of retentive, partially retentive and non-retentive preparation designs on marginal quality was investigated (Fig. 9) after thermo-mechanical loading.[26]

In general, no significant differences of the marginal quality could be found between the three preparations. However, few parallel walls facilitate the placement of the PCCs, because such walls are used for guidance to secure proper seating during luting. However, no sharp edges are allowed, which impair proper seating and correct fit of the restorations. Furthermore, increased shear forces may arise and compromise the strength and longevity of the entire restoration.

The retention rate of PCCs using a defect-oriented preparation design as described above was studied in a number of clinical investigations, and loss of retention was found to be low and mainly dependent upon the luting material and its correct handling (see below).[10,27]

It can be concluded that retentive cavity designs with rather parallel walls are not needed for ceramic partial crowns and a more defect oriented preparation design with only few parallel walls is recommended.

Approximal box depth

The approximal cavity floor with a margin located in dentin has long been considered to be a problem for adhesive restorations in general. Insufficient bonding to dentin and insufficient cavity access with the consequence that the proper technique could not be correctly performed were reasons for bond failure resulting e.g. in secondary caries. However, new bonding systems (see below) have improved the bond to dentin dramatically. Anyhow, it is important that the required steps for good adhesive bonding can properly be executed; thus excellent accessibility also to approximal cavity floors is necessary, especially during luting. Recently, the "proximal box elevation technique" has been introduced as an alternative method to restore large cavities with proximal margins below the cement-enamel junction by sealing the dentin margin with an adhesive/direct composite prior to placement of a direct or indirect restoration in a second step (28). The use of self-adhesive resin cements may not be suitable in this case. Little clinical experience exists with PCCs and the proximal box elevation technique.

Preparation/polishing Instruments

Cavity preparation is usually performed using diamond burs (Fig. 10) with a cylindrical or conical shape and a flat head and rounded edges. Fine grit instruments are recommended for finishing the cavity margins, which – by the way – may also improve bonding of SE adhesives (see below), because the created thin smear-layer allows for better permeation for these substances. Ultrasound preparation instruments can also be used for finishing approximal boxes. Fine grit diamond instruments can also be employed for occlusal and approximal adjustments of ceramic partial crowns. Important is that this adjustment must be performed avoiding heat and crack initiation; water coolant is recommended. Furthermore, ceramic surfaces must be polished following adjustments, in order to prevent/reduce plaque adhesion, increased abrasion of opposing teeth and crack propagation.[18,29] Achieving smooth surfaces depends on a sequential application of all polishing steps.[30] Examples for ceramic partial crown preparations in posterior teeth are shown in Fig. 11.

7. Which adhesive luting material?

Main problems of these materials are the washing out and wear of the luting materials in the luting space, the discoloration and eventually debonding of the restoration. Generally, PCCs fabricated from different silicate based ceramics must be adhesively luted. Suitable materials are composite resins (only light or dual curing materials) in combination with dental adhesives (E&R), self-adhesive cements or compomers (Fig. 12). Resin modified glass ionomer cements (RMGIC) have been marketed for this purpose, but in vitro we have observed problems with one of these materials, leading to fractures of the PCCs after thermo-mechanical loading. This occurred most probably due to expansion after water uptake by the hydrophilic material.[26]

Extensive experience exists with the use of so-called dual cured luting composite materials together with the etch and rinse (E&R) adhesive technique followed by the use of self-adhesive luting materials.

Luting composites

Dye penetration studies with different luting materials have shown superior results in the critical areas (approximal cavity floor in dentin) with the use of a dual curing luting material and an E&R adhesive and of a self-adhesive material[21,31] as compared to compomers. The tested self-adhesive materials initially showed a white line along the luting space, which, however, disappeared after water storage. As ceramic thickness for partial crowns is mainly 1.5 mm or higher, dual curing luting composites are recommended. These materials contain a chemical initiating system, which is sensitive to protons[32] and thus dual curing luting composites should not be used with acidic monomers of self-etch (SE) adhesives. Exemptions are new universal adhesives (see below) or cases in which a separate dual cure activator is used.

Luting composites used together with an E&R adhesive are the standard, showing good esthetics, high bond values both to dentin and to enamel and they provide greatest retention.[33]

Self-adhesive luting materials

These luting materials have been developed and marketed in order to facilitate luting by avoiding a separate pretreatment of dentin or enamel. Laboratory tests had shown that bonding of self-adhesive luting materials to dentin was as good as that with E&R and SE adhesives in combination with a composite luting material, whereas bonding to enamel was compromised.[34-36] Therefore, selective enamel etching was proposed to be used with self-adhesive cements. In a prospective, clinical split mouth study with 34 patients we compared the use of additional enamel etching to that with no separate etching for luting partial ceramic crowns with a self-adhesive luting material. After 6.5 years observation period, additional selective etching of enamel did not offer advantages concerning marginal staining, but revealed better retention rates.[37] However, etching of dentin should be avoided, because bond strength of self-adhesive cements to etched dentin is reduced.[38]

Self-adhesive luting materials are comparatively simple to use and they enjoy a great popularity. A practical advantage is that so-called flash curing is possible: the material is cured for 2-3 seconds, then the surplus material can easily be removed and the final light curing is performed. However, appropriate ceramic pretreatment (etching and silanization) is still necessary and - as was outlined above – the bond strength to enamel is comparatively low (selective enamel etch recommended). Furthermore, desiccation of the dentin before luting should be avoided, because bond establishment and stability are impaired.[27]

Universal adhesives

Recently, a new group of adhesives has been introduced into the market, which can be used with resin-based composites in an E&R or in a SE mode (with and without selective enamel etching), and thus were named "Universal Adhesives". These adhesives are also interesting for luting ceramic to tooth substances as some of the preparations also contain silane substances. The idea is that no separate silane application after ceramic etching is necessary.

Universal adhesives contain acidic monomers. These normally interfere with dual cure luting composites (see above). However, one product (Universal Bond, 3M) was claimed to be compatible if used together with the respective dual cure luting composite from the same company (RelyX Ultimate, 3M), because this luting composite contains a proton scavenger. If other luting composites are used, a separate proton scavenger (dual cure activator) can be purchased and added.

In a prospective clinical split-mouth study with 50 patients we tested the clinical outcome when using this universal adhesive with and without selective enamel etching compared to a self-adhesive luting material.[27] Forty-eight patients were evaluated clinically according to FDI criteria at baseline and 6, 12 and 18 months. After 18 months, retention rates for the group with selective etching were slightly higher (97.6%) than without (95.8%). For both groups retention rates were significantly higher than for a self-adhesive luting material. From these – relatively short term – data it can be concluded that the new adhesives seem to work properly, especially together with the selective enamel etch technique. For all restorations in situ no difference in the clinical behavior (e.g. marginal discoloration) could be observed. The incorporation of a silane into the adhesive and the abandoning of a separate silanization procedure is discussed critically in the literature. Currently, a separate silanization procedure is advocated for.

Resin coating technique/Ceramic Pretreatment

Coating the cavity floors with a thin layer of a flowable resin-based composites prior to impression taking[31] as well as IDS – immediate dentin sealing – are advocated for to protect the freshly cut dentin

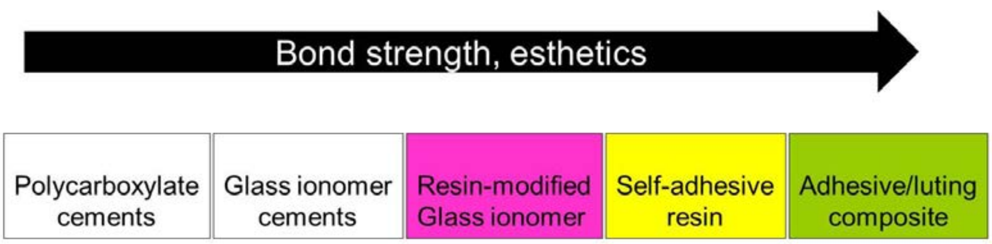

Figure 12. Overview over luting materials partial ceramic crowns. Polycarboxylate cements and glass ionomer cements must not be used for luting PCCs from silicate/disilicate ceramics.

Table 4. Etching and silanization regimens for different ceramic and luting materials.

Ceramic	Self-adhesive resin	Adhesive/luting composite
Feldspatic ceramic, leucit reinforced glass ceramic	60s HF, silane treatment	60s HF, silane treatment, Adhesive
Lithium disilicate ceramic	20s HF, silane treatment	20s HF, silane treatment, Adhesive
ZrO_2 reinforced Lithiumsilicate-ceramic	30s HF, silane treatment	30s HF, silane treatment, Adhesive
Resin containing materials	60s HF, silane treatment	60s HF, silane treatment, Adhesive

following preparation. Furthermore, contamination of the tooth structure during impression taking and temporization is reduced, thus enhancing the establishment of the adhesive bond. Indeed, marginal seal could be improved compared to conventional luting[31] but this technique has not become very popular as it is rather technique sensitive and complex. When using the resin coating technique, final luting must be executed with a luting composite (and not with a self-adhesive material).
Before luting leucite reinforced and lithium disilicate ceramics, they need to be etched and then a silane couple agent has to be applied. The details differ with the ceramic and the luting material (Table 4) These procedures are important, because they significantly improve the bond of the luting composite to the ceramic.

Biocompatiblity

Ceramics are generally considered to be biocompatible and no adverse effects like allergies have been reported. However, luting materials (often resin-based) are needed, and for resin-based materials cases of allergic reactions have been reported. Therefore, care should be exercised to not use luting materials in patients who have a history of allergic reactions to components of this material.[39] Furthermore, luting materials come into close and prolonged contact with dentin and – in deep cavities – potentially with the exposed pulp. Postoperative sensitivity has been observed in few cases in our clinical studies, which abated with time.[10,40] However, in deep cavities with the possibility of pulp exposure, a protective layer of calcium hydroxide cement or a hydraulic tricalcium silicate cement is strongly recommended.[39,41]

8. Light curing: irradiance, time?

Light curing is facing two problems: too little light applied, which may result in insufficient curing, less retention, wash-out and marginal discoloration or too much light applied, which may lead – especially when applied in a short time – to overheating. Insufficient light output may be due to insufficient instruments[42] or due to an insufficient technique;[43] e.g. when the tip of the light guide is not directed correctly to the restoration. Secondary caries has been associated with insufficient curing of resin-based composites but also increased release of substances from the materials and thus increased cytotoxicity.[44,45] Too much energy delivered by the light curing units may result in heat damage adding to the heat produced by the exothermic setting reaction of the luting composite. High energy light curing units have recently been marketed with an irradiance of > 6000 mW/cm^2.
Dentin has a low thermal conductivity.[46] As a rule of thumb, 16 J/cm^2 are needed for optimal curing of a resin-based composite (e.g. 800 mW/cm^2 for 20 seconds, or 1600 mW/cm^2 for 10 seconds. However, this rule (increasing irradiance while reducing irradiating time) cannot be extrapolated to very high energy levels and very short times like few seconds.[47] Compressed air reduced temperature increase.[48]
Polymerization rate is dependent on the light energy which reaches the luting material. Thus color, translucency and thickness of the ceramic and the distance between the tip of the light guide and the ceramic surface play an essential role when choosing the right amount of energy.[49,50]

Ceramic thickness

In an in vitro study measuring the depth of cure and the Vickers hardness of a standard luting composite, Jung et al.[51] found that with a leucite reinforced silicate ceramic (IPS Empress) and 2 mm ceramic thickness, at 40 sec 800 mW/cm^2 dual curing leads to a significantly better polymerization than light curing only. For a leucite reinforced ceramic of a thickness of 1 mm, light curing alone resulted in the same cure as that with an additional chemical cure.[49,52]

Translucency

For leucite reinforced silicate ceramic and for lithium disilicate ceramic, which is less translucent than the leucite reinforced material, similar curing of a dual curing luting composite occured with a ceramic thickness of 1 mm. For a larger thickness, significant differences were observed.[49] Follow meticulously the information of the manufacturer: ceramics with little translucency or dark colors require extended irradiation times.

Recommendation

- Generally, eyes of the dental personnel should be protected, e.g. by a shield at the end of the light guide.
- For posterior teeth, the use of a dual curing luting composite is highly recommended. For a standard light curing unit with an irradiance of around 800 mW/cm^2, an irradiation time of 40 seconds from occlusal and additional from oral and vestibular are recommended.[49]
- Irradiance levels of 800 to 2000 mW/cm^2 are regarded as standard. With light curing units emitting higher radiances, little clinical experience exists, and heat effect on the pulp or burning of lips should be prevented; rubber dam provides no protection.[53]

9. Step by Step checklist

- Case selection/Prevention program: as luting resins may enhance bacterial growth and biofilm vitality,[54,55] excellent oral hygiene and participation in a structured recall system for monitoring and controlling oral hygiene measures is a prerequisite for successful long term results.

• Indication: large cavities needing cusp replacement.
• Preparation: defect oriented, create enough space for at least 1.5 mm ceramic thickness; no classical retention but guidance for insertion.
• Temporization: chairside using an impression taken before preparation, filling it with a temporary resin-based composite, placing it onto the prepared teeth and removing after setting. Temporaries should be luted with a eugenol-free material although the influence of eugenol on the final curing of luting composites is subject to discussion. In any case, more important is the careful removal of temporary cementation materials from the cavity prior to luting[56] using e.g. air polishing with glycin; calcium carbonate air polishing generally caused significantly reduced dentin bond strengths.[57]
• Lab work can be performed in the dental office or in the dental laboratory
• Try in of the restoration and careful adjustment of approximal and occlusal surfaces avoiding high pressure (heat), which may lead to ceramic fractures or to crack initiation; try in paste can be used to check for esthetics but must be carefully removed prior to bonding.
• For certain materials like lithium disilicate ceramic for CAD/CAM chairside application, further lab work (final painting, glazing, improving strength) is necessary.
• Pretreatment of the ceramic: Etching of the ceramic (silicate glass ceramic), silanization (see Table 4)
• Self-adhesive luting materials: ceramic pretreatment, additional selective enamel etching
• Luting composites with E&R adhesives: Separate curing of the adhesive improves bond strength.[58]
• Luting composites with universal adhesives: E&R is possible with all products; SE (with and without selective enamel etching) with certain products (see manufacturer information)
• light curing: e.g. 40 seconds/800 mW/cm^2 on three sides; be careful with high power light curing units (> 3000 mW/cm^2).
• Rough surfaces are abrasive to opposing enamel and reveal lower resistance to crack propagation,[18,29] polishing using e.g. silica, silicon carbide or diamond impregnated rubber polisher.[18]
• Ceramics and luting materials differ between manufacturers: it is essential that the specific recommendation of each manufacturer provided for the specific materials are followed meticulously.

Author Contributions

GS has drafted the manuscript. MF has added relevant information and a number of figures.

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Gottfried SCHMALZ

DMD, PhD, Professor Dr, Dr. h.c.
Department of Operative Dentistry and
Periodontology Medicine Faculty, University Hospital Regensburg
D-93052 Regensburg, Germany

CV

Gottfried Schmalz, DDS, Dr med dent, PhD, is the former chair and current professor at the Department of Operative Dentistry and Periodontology, University of Regensburg, Germany. He is a member of many scientific organizations and has won numerous awards, e.g. the Distinguished Scientist Award of the IADR and the Award of Excellence of the European Federation for Conservative Dentistry. He is the editor of the book 'Biocompatibility of Dental Materials'; he has authored 5 books and more than 260 publications listed in PubMed. He has been Editor-in-Chief of "Clinical Oral Investigations", since 1996 and Honorary Editor since 2016. Since 2016 he is chairman of ISO (International Organization of Standardization) Technical Committee 106: Dentistry. His main scientific interests are material/tissue interactions, oral tissue regeneration and ceramic restorations.

Questions

What are the main reasons for PCCs failure?

❑a. Ceramic thickness less than 1 mm
❑b. Endodontic treatment
❑c. Subgingival location of approximal margin
❑d. Use of silicone polishers

What are the most important rules for a correct PCC cavity design?

❑a. Box preparation with as many as possible nearly parallel walls
❑b. No subgingival margin
❑c. Cavity oriented design with few parallel walls
❑d. Sharp edges inside the cavity to improve adhesion

What are the clinical advantages of reinforced silicate ceramics?

❑a. good esthetics
❑b. highest strength of all ceramics
❑c. most easily to handle
❑d. can be luted with glass ionomer cement

Which material is most suitable for luting reinforced silicate PCCs

❑a. Glass ionomer cements
❑b. Phosphate cement
❑c. dual curing resin-based composites
❑d. resin-modified glass ionomer cements

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