Effective protocol for daily high-quality direct posterior composite restorations. Cavity preparation and design.

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Abstract

Tooth-cavity preparation contributes to a large extent to the quality of the direct posterior composite restoration, the so-called hidden quality of the restoration. Indeed, the effect of a poor cavity design is not immediately visible after placement of the restoration. To correctly prepare a cavity for a posterior composite restoration, the tooth to be restored should first be profoundly biomechanically analyzed. Here, the forces that work in on the tooth during occlusion and articulation, and the amount and quality of the remaining tooth structure determine the cavity form. In addition, the dental tissues must be prepared in order to receive the best possible bond of the adhesive and subsequent restorative composite. A well-finished cavity preparation enables the restorative composite to adapt well, providing a good marginal seal to the direct benefit of the clinical lifetime of the posterior composite restoration. Finally, it is highly recommendable to isolate the teeth with rubberdam before starting with the cavity preparation, as this increases the visibility of the workfield and allows the operator to work in a more precise way.

Introduction

Nowadays composite is the first-choice direct restorative material for class-1 and class-2 restorations in the posterior region (46). A growing body of evidence has demonstrated that the clinical survival of posterior resin-based composite restorations exceeds 90% after five years and 80% after 10 years (1,5,15,44,60,61). The main reasons for failure are marginal gap formation, secondary caries and fracture of the restoration (39,61). The success of a posterior composite restoration is not only material-dependent, it is also linked to patient-related factors, such as bruxism, caries risk and socio-economic status, to tooth-related factors, such as the amount and quality of the residual tooth structure, and finally also to operator-related factors (8,14,15,43,44,61,86,87). Placement of a direct composite restoration in the posterior region is a technique-sensitive procedure. The operator must select the proper materials and conduct the treatment protocol correctly. To date, several aspects of direct posterior composite restorations (composite selection, layering protocol, cavity preparation, adhesive protocol, and others) have abundantly been studied *in vitro* and *in vivo*. However, the complete A-to-Z clinical protocol for placement of a direct posterior composite restoration has rarely been described in detail. It is the aim of the authors to present in three articles an effective protocol to place daily high-quality direct posterior composite restorations.

In an organized dental practice, the average time scheduled for placement of a class-1/2 direct composite restoration, from simple to complex - by an experienced operator- varies between 20 to 60 min. In this time span, the dentist must be able to perform a high-quality posterior composite restoration following a standardized and effective protocol (Fig. 1). The protocol consists of 7 steps: 1. Biomechanical analysis; 2. Field isolation; 3. Cavity preparation; 4. Selection and placement of the matrix system in case of a class-2 restoration; 5. Adhesive protocol; 6. Layering of composite; 7. Finishing and polishing (Fig. 2). For the dental practitioner, restoring a moderately destructed posterior tooth with wide open boxes and cusp reduction with a high-quality direct composite restoration is demanding, especially from a practical point of view. Critical aspects concern obtaining good marginal adaptation, correct occlusal anatomy, well-contoured proximal walls with strong and well-positioned contact points, and correct buccal/lingual and proximal emergence profiles (Fig. 3). Although these extensive direct composite restorations, when correctly placed, perform well in non-bruxing patients in the medium term (17,41,69), the most optimal and durable restoration for a moderately destructed posterior tooth is a bonded indirect ceramic onlay/partial crown (65) (Fig. 4). As part of a series of three papers, the present article addresses the biomechanical analysis, isolation and cavity preparation for class-1, class-2 and cusp coverage preparations. The second article will describe the adhesive protocol, composite layering, finishing and polishing of the posterior composite restoration. Finally, the last article will focus on the tips and tricks to create an adequate interdental anatomy when placing a class-2 composite restoration, including selection of the most suited matrix band.

Biomechanical analysis

Dental tissues respond biologically to stress and strain imposed during mastication (92). Teeth compromised due to carious lesions or restorations tend to weaken the tooth structure. Stress in teeth associated with these conditions may lead to cusp fracture. It is essential to prevent fractures by starting from a clear concept with a sound tooth-preparation design and by anticipating the stress of mastication that may be imposed on the remaining tooth structure. For these reasons, the restorative procedure of a bonded direct (indirect) restoration in the posterior region should always start with a profound biomechanical analysis of the tooth. This includes estimation of the forces and loading on the tooth during occlusion and articulation, as well as analysis of the amount and quality of the remaining tooth structure (Fig. 5).

1. Evaluation of the forces that affect the tooth during occlusion and articulation

The chewing forces and occlusal loading imposed on a tooth are determined by the anatomic position of the tooth (52). The more the tooth is located towards the posterior region (from first premolar towards second molar), the more heavily the occlusal loading, resulting in an increased risk of fracture (43,61). The presence of cracks and wear facets indicate heavy occlusal loading. In a physiologic condition, the maximum bite force on a first molar varies between 450 and 800 N (bilateral measurement) (9,52,88,89). In patients with parafunction (bruxism), this value can increase up to six times (32,40).

Occlusion and articulation on the tooth that needs to be restored should be registered in advance with articulation paper, this in order to analyze the strength and location of the occlusal contacts at the future restoration margins and on the remaining cusps. Attention must be paid if the antagonist is erupted and/or if the adjacent tooth is tilted, as this will determine the final occlusal morphology of the direct composite restoration. Taking this into account during layering of the composite restoration, the finishing time will be reduced.

2. Evaluation of the amount and quality of the remaining tooth structure and resistance to masticatory loads

During cyclic and dynamic occlusal loading, the occlusal forces continuously act on the restored tooth. The remaining amount and quality of tooth structure will determine the fracture resistance of the (restored) tooth. Several *in-vitro* studies evaluated the influence of cavity type, isthmus width and cavity depth on the fracture resistance of the prepared/restored tooth (7,22,23,24,25,33,49,50,55,56,63,66). The amount of reduction in fracture resistance of the different cavity designs varies among these *in-vitro* studies and can be explained by differences in study design (premolars/molars, variations in size and depth of the cavity preparation, test method). Nevertheless, similar general trends were recorded (Figs. 6a,b).

Isthmus width: A significant decrease in fracture resistance was recorded when the isthmus width increases from 1/4 to 1/3 or to 1/2 from the intercuspal distance in class-1 and class-2 cavities (MO, DO, MOD) (13,42,55,57,66,79).

Marginal ridge and other reinforcing structures: Several *in-vitro* studies emphasize that conserving the marginal ridge is a fundamental factor in limiting abnormal cuspal deflection and breakdown (23,49,55,56,63,66) (Fig. 6b). The fracture resistance of teeth with cavities gradually decreases for teeth with only an occlusal class-1 cavity, to teeth undermined by a two-surface class-2 cavity, and finally to teeth exhibiting a three-surface MOD cavity preparation having the lowest fracture resistance. After restoration of a normal-size MOD cavity with a direct composite restoration, several forces work in on the adhesive interface. On the one hand, the cusps will move slightly outwards during occlusal loading. Depending on the size of the cavity and the study design, this movement varies from 7 to 30 µm (48,49,23,25). On the other hand, there is an inwards movement of the cusps due to polymerization shrinkage, varying from 5 to 40 µm (24,25,38,81). Determining parameters are type of composite, premolar vs. molar, shape, size and depth of the cavity, intensity of the polymerization light-curing unit, adhesive and composite placement technique (18). A high-quality bond between the tooth and the composite restoration must be able to resist all these sorts of stress at the interface. If the adhesion is not optimal, de-bonding will occur and the cavity walls will flex during occlusal loading. This can result in partial/total loss of adhesion, gap formation and finally fracture of the cusps (Fig. 6c).

In addition to the marginal ridge, the *oblique crest* on an upper molar and the *transversal crest* (premolars, molars) are also reinforcing structures for the tooth (47,53). If they are not strongly undermined by caries, these structures must be maintained in class-1 and class-2 cavities (Fig. 7).

Cavity depth and width: The cavity width and depth largely determine the fracture resistance of the tooth (7,19,22,23) (Fig. 8). In an *in-vitro* study of Forster *et al.* (19), the depth of MOD cavities in molars determined the fracture resistance much more than the cavity width did. When the cavity depth was 5 mm or more and the teeth were restored with a direct composite restoration, the fracture resistance of the molars could no longer be restored up to the physiological fracture strength. These results rather suggest that a cavity of 5 mm depth is already in the “danger zone” in case it will be restored directly with composite without cusp coverage.

Similarly, several *in-vitro* studies showed that large MOD cavities resulted in a decrease in fracture resistance by 59% to 76%, as compared to that of intact teeth (13,66,75,79) (Fig. 9a).

Endodontic treatment: Reeh *et al.* (66) observed that premolars with a small endodontic access and preservation of the interaxial dentin, showed a reduction in cuspal stiffness of only 5%. In combination with a medium-size class-1 cavity, a reduction of 25% was observed (Fig. 6a). Several *in-vitro* studies recorded a strong reduction in fracture resistance/cuspal stiffness in endodontically treated PM/M with a MOD cavity (19,20,23,63,76). The loss of both marginal ridges in combination with removal of the para-pulpal dentin resulted in severe weakening of teeth (Fig. 9a). Increased cuspal deflection may intensify the shear forces at the adhesive interface, resulting in debonding of the adhesive from the cavity wall, which may result in higher occurrence of fractures and secondary caries (Fig. 9b).

A similar observation was made in a long-term (6-13 yrs) *in-vivo* study evaluating class-2 direct composite restorations in the premolar/molar (PM/M) region (44). The experimental group of restored endodontically treated PM/Ms showed an increased failure rate compared to restored vital PM/Ms. The failures observed in the group of non-vital teeth were cusp and vertical root fractures. These failures were never recorded in the group of vital teeth. Endodontically treated PM/Ms also showed a higher frequency of secondary caries, compared to the restored vital PM/Ms, although the caries risk in this patient population was low. Among the evaluated risk factors, occlusal stress negatively affected the survival of direct composite restorations in endodontically treated teeth. The latter *in-vivo* study confirms that a profound biomechanical tooth analysis is required to guide the cavity design towards a durable tooth restoration. Cavity preparations that strongly weaken the tooth, such as deep and wide (occlusal and MOD) cavities including endodontically treated teeth, should be restored by covering the cusps and subsequent placement of an adhesively luted onlay or partial crown (19,20,23,63,67,76).

Isolation

After adequate anesthesia, the working field should be isolated. Rubberdam isolation is an absolute requirement for controlled adhesive procedures during placement of a direct posterior composite restoration. The benefits of rubberdam isolation include moisture control, prevention of bacteria and saliva contamination, increased visibility and access to the working field. Moreover, it improves tongue and lip control, reduces airborne debris, prevents gagging, prevents aspiration of restorative materials and instruments, reduces procedural operating time and improves treatment quality and patient comfort (6,83). It is difficult to scientifically prove the impact of rubberdam application on the final outcome of treatment. In a meta-analysis, evaluating the clinical effectiveness of direct class-2 composite restorations, placement of rubberdam had a significant effect on the overall restoration longevity (30). Restorations placed with rubberdam showed fewer material factures during clinical follow-up, and fewer restorations needed replacement. A Cochrane review by Wang *et al.* (90) reported that there is some evidence to suggest that the use of rubberdam may increase the survival time of dental restorations compared to the use of cotton rolls as an isolation method. However; the evidence presented was of very low quality due to the small number of available studies, uncertain results and problems with the way in which the available studies were conducted.

To be effective, it is important that the rubberdam is correctly placed and results in absolute isolation. A clear and simple protocol must be followed (6). It is beyond the scope of this article to describe isolation with rubberdam in detail. Only some fundamental tips are given (Fig. 10): 1. Before placing the rubberdam, the dentist must check the accessibility of the proximal contact points, so that the rubberdam easily passes throughout the interproximal areas. 2. It is useful to isolate many teeth in the quadrant where the tooth/teeth need to be restored, as this provides the operator with reference points during layering of the composite restoration regarding anatomy and occlusal plane. In addition, quadrant isolation increases the visibility of and access to the operation field. 3. If possible, an anchor clamp (e.g. 26N, 27N or W8A; Hu-Friedy; Frankfurt am Main, Germany) is placed on the tooth distal to the one that requires the restoration. It is preferred to isolate minimum two teeth mesially of the tooth to be restored. 4. To reach good sealing of the rubberdam near the gingiva, the rubberdam must be inverted. Floss ligatures are used, only when necessary (when restoring class-2 lesions with subgingival margins), as floss absorbs a lot of moisture. 5. Finally, teflon tape and a retraction cord can help in complex isolation cases (deep boxes, subgingival margins) (6,70) (Fig. 10b). With practice it becomes possible to successfully isolate deep subgingival margins.

Cavity preparation and design

Cavity preparation and design is an important step in the clinical protocol as it determines the quality of the direct posterior composite restoration to a great extent. Nowadays, quality is a key concept in restorative dentistry. In this respect, both ‘hidden’ and ‘perceived’ quality should be taken into account. Whereas the final esthetic result is ‘perceived quality’, cavity preparation and design largely determine the ‘hidden quality’ of the restoration. The effect of a suboptimal cavity design will become visible after some months or years of clinical functioning.

Detailed guidelines of cavity preparations for direct posterior composite restorations are scarce in the literature. Some review articles merely emphasize the minimally invasive aspect of cavity preparation: only caries needs to be removed with all remaining tooth structure kept for bonding (29,46,68). However, the biomechanical aspect of the tooth to be restored, as described above, was not taken into account in these reviews.

A proper protocol of the cavity preparation and design consists out of 4 steps (Fig. 11).

1. Make access to the caries lesion

After rubberdam isolation, access to the caries lesion is obtained with a diamond bur (Figs. 11d,e). If there is caries underneath an existing restoration, the restoration is removed with a diamond bur (composite) or a multiblade tungsten carbide bur (amalgam). Next, the cavity walls and the floor of the cavity (removal of existing liner) are cleaned with a round multiblade tungsten carbide bur at a low speed (7000 rpm) to expose the carious lesion (Fig. 12).

2. *Removal of carious dentin*

Carious dentin presents in two forms: infected and affected dentin. Caries-infected dentin consists of a superficial necrotic zone of vastly demineralized substrate (2,58,59), with degenerated collagen fibrils that have lost their cross-linking. It may also be considered as a bacterial biomass (3). The consistency of this dentin is soft or leathery. Conversely, caries-affected dentin has a certain hardness and is considered to be a variation of reactionary dentin, formed in reaction to bland stimuli like caries; it presents small alterations in cross-linking of its collagen fibrils (2,58,59). Additionally, it contrasts with sound dentin by mineralized precipitates within the tubules (54). Investigations disclosed that caries-affected dentin may be remineralised (82,93).

Today's adhesives bond effectively to sound dentin through hybridization. Nevertheless, this bonding mechanism remains vulnerable in the long term. Incomplete resin envelopment exposes collagen to oral fluid attack and enzymatic degradation processes that may eventually lead to caries recurrence

(85). Bonding to caries-affected dentin is less predictable and durable, not only because of wider zones of unprotected collagen (26), but also because more cracks and pores are present (34). The bond strength to caries-infected dentin is even significantly lower than that to caries-affected dentin (10,94). A systematic review evaluating bonding effectiveness to caries-affected dentin showed that a clean and sound dental substrate is an important requisite for adhesion and adhesive dentistry (36). Indeed, if the operator aims to obtain the best possible bond to dentin, all affected dentin should be removed during cavity preparation, resulting in a good quality hard dentin surface (Figs. 11m and 12).

In a first step, a sharp hand excavator is used to check the dentin consistency and to remove the soft carious dentin (74) (Figs. 11h-j). A multiblade tungsten carbide bur is not yet indicated, as the blades of the bur become compacted with the soft caries tissue, strongly decreasing the bur's cutting efficiency. In a second step, the infected/affected dentin is further removed with a multiblade tungsten carbide bur (Komet H1SEM; Brasseler, Lemgo, Germany) until the dentin surface is hard and clean (Figs. 11l,m). The bur is used dry and with low speed (7000 rpm). The caries will be removed following a centripetal approach, from the periphery to the critical points in the center, this in order to program possible pulp exposure.

The rationale of cavity preparation presented by the authors is somewhat different from the modern concept of 'minimally invasive dentistry', which promotes a more conservative elimination of the highly infected and irreversibly demineralized carious tissue. In minimally invasive dentistry, clinicians are advised to remove carious dentin to the level where it is 'affected or firm' (71). Doing so, they may leave demineralised dentine that is judged to still possess some remineralisation/healing potential on the cavity floor. In deep caries lesions, a selective caries-removal technique is advised in teeth with vital asymptomatic pulps. In the periphery of a cavity, removal to hard dentin is performed, while in pulpo-proximal areas, leathery or soft dentin is left to avoid pulp exposure and to keep the pulp vital. Studies targeting pulp vitality and dentin reactions have shown the beneficial effects of this therapy (4,37,45). However, very few studies evaluated the biomechanical aspect of the inferior bonding capacity of adhesives to caries-infected dentin, especially in deep and wide cavities. Hevinga et al. (31) analyzed the immediate fracture strength of extracted molars with natural deep caries lesions receiving composite restorations placed over residual caries. A significant reduction of fracture strength was recorded for the teeth restored after SCR compared to a control group submitted to complete caries removal (CCR). Schwendicke et al. (72,73), studying extracted premolars with artificial caries lesions restored after SCR, found a significant increased cusp deflection, while fracture resistance and marginal integrity was not significantly influenced by the caries removal technique (SCR versus CCR). In addition, some clinical trials evaluating the SCR technique in the primary dentition show that in spite of the higher rates of pulp reservation, the composite restorations fail more frequently compared to the CCR technique (45,64). Future clinical studies with good study design are needed to evaluate the biomechanical aspect of the inferior bonding capacity of adhesives to caries-infected dentin in permanent teeth, especially in deep and wide cavities on the medium to long-term.

In case the practitioner would like to leave caries-infected/affected dentin in the depth of the cavity, in order to keep the pulp vital, this dentin is recommended to be covered with a remineralizing material like a calcium-silicate cement or a glass-ionomer (28,84). Nowadays, there is considerable evolution in the development of bioactive and remineralizing restorative materials that can be used in these indications. However, we still have to wait for their clinical proof.

According to the guidelines of the European Society of Endodontology, regarding management of deep caries and the exposed pulp, direct pulp capping with complete caries removal is another treatment option that must be included when treating asymptomatic vital teeth with deep caries lesions (11,16). The prognosis of direct pulp capping is determined by a correct diagnosis of the pulpal health, use of adequate materials, sterile instruments, magnification, absolute rubber dam isolation, full caries excavation as well as the possibility of immediate and definite bacteria-proof seal. It is beyond the scope of article to discuss the topic of vital pulp treatment.

For the treatment of a proximal caries lesion, a box will be prepared. The box must be opened until interproximal clearance is achieved. It means that the buccal and lingual/palatal margins of the box are made accessible (Figs. 11o,q and 13c). This allows the operator to place the matrixband in a passive way, without any risk of distortion. Another advantage of interproximal clearance is that the buccal and lingual margins of the box can be finished and polished well, as they are clearly visible and accessible. In addition, in a later stage, during a recall session, it is easy to re-polish these accessible margins.

When there is direct access to the proximal caries lesion, the marginal ridge can be preserved, on condition that residual dental tissue at the marginal ridge is thick enough and the marginal ridge is not overloaded during occlusion and articulation (Fig. 14).

3. Evaluation and removal of undermined enamel

After removal of the existing restoration and decayed dental tissue, a second detailed biomechanical analysis takes place and the final decision to potentially cover the cusps is made. The following guidelines are proposed (Fig. 15):

- If the remaining cusp has a thickness of 2 mm or more and enamel is supported by dentin, the cusp is kept.
- Similarly, with a cusp thickness of around 2 mm and slightly undermined enamel (on average 1 mm), the cusp can be kept if it is not heavily loaded during occlusion and articulation (Fig. 15a).
- Strongly undermined cusps (enamel not supported by dentin) should be reduced to at least 1.5 mm and capped (Figs. 15b-17). The more the height of the cusp is reduced, the less dentinal support is needed. With a strongly reduced lever arm, the risk of flexure of the cavity wall is also strongly reduced. This means that in the cervical area, one can end with the margin in enamel (as this is the best tissue to bond to) and have slightly undermined enamel. The same rationale is followed in the proximal box area (Fig. 18).

Other indications for cusp reduction are: horizontal crack underneath one or more cusps, too wide (isthmus width > 1/3-1/2) and deep cavity, MOD cavity with a longitudinal crack, MOD cavity in an endodontically treated tooth, and an endodontically treated tooth with a crack in the pulp chamber.

4. Finishing the cavity

Finishing of the cavity is important as this results in increased wettability and adaptation of the adhesive layer, improved adaptation of the composite resin, better marginal sealing of the restoration, better adaptation of the matrix band, all to the benefit of increased longevity of restoration (29,46,68).

The finishing protocol includes 3 steps.

1. Sharp internal angles of the cavity are rounded with a multiblade tungsten carbide bur (Komet H1 SEM). Rounded internal angles should be the norm, given the cusp-weakening effect of angular line- and point angles. In addition, composites tend to adapt much better in cavities with rounded rather than sharply defined internal architecture (46) (Fig. 19).

2. To be sure that the prepared cavity is clean with a thin and light smear layer, tooth preparation is finalized by airborne-particle abrasion with Al_2O_3 powder (30 or 50 µm) (Fig. 20). Air abrasion is reported to increase the surface roughness and surface area available for adhesion and improve resin adaptation (21,27,35,51). Several *in-vitro* studies showed increased bond strength to air-abraded dentin using an etch-and-rinse or a self-etch adhesive (27,51,80). Other *in-vitro* studies, however, measured neither significant influence of air abrasion on the bond strength to enamel and dentin nor for etch-and-rinse adhesives, nor for self-etch adhesives, not even after aging (35,95). Soares *et al.* (77) and Ouchi *et al*. (62) observed that air abrasion of bovine dentine with 50 µm Al_2O_3 powder adversely affected the bond of self-etch adhesives. In the last study, the authors speculated, based on the integrated results, that a compressed dentin smear layer and embedded alumina particles may interfere with the penetration of the resin monomer and interaction with the functional monomer of the self-etch adhesive (62).

3. The final step in the cavity preparation is finishing the enamel margins. An enamel bevel is not indicated, as this more easily results in cracking of the enamel at the margins (29,46,78). In addition, the composite layer will be too thin in the region of the enamel bevel. To finish the enamel margins, the sharp, unsupported enamel prisms of the occlusal and proximal (buccal and lingual) cavity margins will be removed with a flame-shaped diamond bur (40 µm grit), to be used dry and with medium speed (Fig. 21). The finished margins may not be located in demineralized enamel in order to prevent early caries recurrence.

The cervical margin of the box will be finished (straight margin) with a conically shaped microfine diamond bur (40 µm grit). The sharp and irregular enamel prisms at the cervical margin will be removed with a metal diamond strip (Fig. 21b). Sono-abrasion can also be used to finish the proximal cavity margins (12,91)(Fig. 22). The sono-abrasion technique makes use of different forms of one-side diamond coated oscillating preparation tips. Using the handpiece on low power allows fine and non-traumatic control during finishing of the enamel margins. The main advantage of this technique is prevention of iatrogenic damage to the adjacent tooth (Fig. 22b). Special tips are available to finish the cervical margin of the box (e.g Sonicflex Micro tip and Sonicflex Prep CAD/CAM tip; Kavo Dental, Biberach/Riß, Germany; EMS tips SM and SD, DS 051A and 052A; Nyon, Switzerland*)*, while blade- or lance-shaped tips (eg. Sonicflex shaping tip; Kavo Dental) are usefull to finish the buccal and lingual margins of the proximal box. A hemispherical micro tip (e.g Sonicflex Micro tip; Kavo Dental) can be used to prepare small interproximal cavities (Fig. 22d-f).

As a conclusion, the final cavity preparation is characterized by a clean and sound dental substrate, smooth transitions inside the cavity, no sharp angles, an acceptable isthmus width, removal of undermined enamel where needed, interproximal clearance in a class-2 cavity, and well-finished cavity margins (Fig. 23).

Conclusion

Cavity preparation is an important step in the protocol to make a high-quality direct posterior composite restoration. After caries removal, the pathologic cavity must be converted into a therapeutic cavity. This includes that the cavity will be adapted taking into account the observations made during a profound biomechanical analysis. This analysis determines if undermined enamel must be removed and the cusp(s) reduced. Rounded internal cavity angles and well-finished cavity margins will result in a good adaptation of the resin composite with a tight marginal seal. Consequently, paying attention to these cavity-preparation guidelines will contribute to an increased longevity of the posterior composite restoration.

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Figure legends

Figure 1: (a) Situation before: the patient asked for replacement of the existing amalgam restorations because of health reasons. In addition, the second molar showed a caries lesion at the mesial side. After a first biomechanical analysis, the operator observed that enough sound tooth structure was left to restore the teeth in a durable way with direct composite. (b) After having given local anesthesia, the teeth were isolated with rubberdam and decontaminated by air-polishing with sodium-bicarbonate powder (25-50 µm). (c) The existing amalgam restorations were removed. A box was prepared at the mesial side of the second molar in order to have access to the proximal caries lesion. (d) The cavity preparations were finished. The internal cavity angles were rounded, sharp irregular enamel prisms at the cavity margins were removed and the cavities were sandblasted with air abrasion (30-µm Al_2O_3 powder). (e) Two weeks after placement, the final composite restorations were well integrated in the surrounding natural tooth structure. The time needed to place these three high-quality direct posterior composite restorations was 90 min.

Figure 2: The protocol for placement of a direct posterior composite restoration consists of 7 steps: biomechanical analysis, isolation, preparation, placement of matrix system (class-2), application of the adhesive, layering of the composite and finishing/polishing of the composite restoration. For an experienced operator, the average time schedule for placement of a class-1/2 composite restoration, from simple to complex, varies between 20 to 60 min.

Figure 3: (a) Restoration of a quadrant with direct composite overlays. The critical steps in the placement of these large direct composite restorations are control of marginal adaptation, correct occlusal morphology and contact points, strong and well-positioned proximal contact areas, and a correct buccal/lingual and proximal emergence profile. (b). The restorations are clinically acceptable and can function quite well in the medium term in this non-bruxing patient with low caries risk.

Figure 4: (a) After removal of the old amalgam restoration on the second upper molar, a large amount of caries was found. The operator decided to restore this moderately affected tooth in the most durable way with a bonded indirect ceramic partial crown. (b) The tooth was prepared for a non-retentive bonded ceramic onlay. After caries removal, the exposed dentin was protected with a layer of immediate dentin sealing and the undercuts were blocked out in a micro-selective way with a flowable composite. The preparation margins are located in enamel. (c) A bonded lithium-disilicate glass-ceramic onlay was bonded with a light-cure restorative composite. Working in an indirect way provides control on occlusal morphology, the proximal contact points and emergence profile of the tooth to be restored. (d) The buccal emergence profile of the first molar is well aligned with the adjacent intact teeth. It is quite impossible and time-consuming to realize this with a direct composite build-up.

Figure 5: (a) Initial situation. Old unacceptable amalgam restorations on 45, 46 and 47 needed to be replaced after orthodontic treatment. Registration of the occlusion shows that the teeth are not heavily loaded. After evaluation of the quality and the amount of remaining tooth structure, it was decided to restore the second premolar and second molar with a direct composite restoration. The first lower molar shows several deep cracks in the surrounding tooth structure. To restore this tooth in a durable way, the cusps needed to be reduced. A bonded indirect lithium-disilicate glass-ceramic partial crown was planned. (b) An X-ray informs the dentist about the possible depth of the final cavity. The depth and width of the cavity determine to a large extent the fracture resistance of the teeth to be restored. (c) At the buccal side, the first molar showed an unacceptable composite restoration and deep cracks in the surrounding tooth structure, indicating the need to restore this tooth with an onlay. (d) The teeth are restored with bonded high-quality restorations. The restorations are adapted according to the size and depth of the lesions. The first molar was restored with a bonded indirect lithium-disilicate glass-ceramic partial crown, while direct composite restorations were placed on the second premolar and second molar.

Figure 6: (a) Influence of the different types of class-1 cavities on the fracture resistance of the tooth. Reeh *et al.* (66) recorded a decrease in fracture resistance of 20% when a medium size class-1 cavity was made. In combination with limited endodontic access, the fracture resistance decreased up to 25%. Most unfavorable is a wide and deep class-1 cavity. The fracture resistance of these teeth can decrease up to 70% (33). (b) Influence of the different types of class-2 cavities on the fracture resistance of the tooth. The marginal ridge contributes to a large extent to the fracture resistance of the tooth. In addition, the isthmus of the class-2 cavity also plays a role. Small isthmus MO: 20% reduction; medium isthmus MO/DO: 46% (66); small isthmus MOD: 50% reduction (57). (c) A high-quality bond between tooth and composite restoration must be able to resist the stresses that develop at the adhesive interface during placement of the composite (due to polymerization-shrinkage stress) (orange arrows) and occlusal loading (blue arrow). If the adhesion is not optimal, loss of adhesion will occur and the cavity walls will flex during occlusal loading (red arrows). This can result in partial/total loss of adhesion, gap formation (red line) and finally fracture of the cusps.

Figure 7: (a) Initial situation: small caries lesions must be treated on the first molar (occlusal lesion) and on both premolars (proximal lesions). (b) The finished cavity preparations. The reinforcing structures of the tooth, the oblique ridge and transverse ridges, were maintained. The various small cavities on the occlusal surface of the first molar were not connected. Maintaining these reinforcing structures contributes to the fracture resistance of the teeth to be restored. (c) After placement of the direct composite restorations.

Figure 8: The width and depth of the isthmus largely determine the fracture resistance of the teeth to be restored. Restoring a wide and deep cavity, such as one on the distal side of the first lower molar, with a direct composite restoration creates considerable tensile stresses at the adhesive interface during occlusal loading. This may result in loss of adhesion, flexure of the surrounding

cavity walls, and eventually tooth fracture after short/medium term clinical functioning. On this tooth, the cusps must be reduced and the tooth restored with an onlay. The cavity on the second molar has an acceptable width and depth and can be restored with a high-quality direct composite restoration. The DO cavity on the second premolar is a bit wider and deeper, but a lot of remaining sound tooth structure is left at the mesial side. When restoring this tooth with a direct composite restoration, the surrounding tooth structure will not flex so easily during occlusal loading.

Figure 9: (a) The most unfavorable situation regarding fracture resistance are premolar (PM)/molars (M) with a large and deep class-2 MOD cavity and endodontically treated teeth with a MOD cavity. Large and deep MOD cavities result in a decrease in fracture resistance by 59% to 76% compared to that of intact teeth. Endodontically treated PM/M with a MOD cavity show a strong reduction in cuspal stiffness. The cusps can flexure up to 100 µm (63). (b) Aged MOD fillings (with a wide and deep cavity) often fail after prolonged service. Such degradation is generally attributed to the onset and progression of interfacial marginal fissures, associated with repeated mechanical and thermal stress imposed in a hostile aqueous environment, in combination with composite shrinkage and interfacial leakage. This occurs more easily when the adhesive procedure is not carried out correctly, and when less efficient adhesives are used. Continuous propagation of such marginal fissures may ultimately lead to fracture of the surrounding tooth structure.

Figure 10: (a) In this patient, the dentist planned to replace the amalgam restoration on the first molar because of caries recurrence at the mesial side. Before starting with the cavity preparation, the teeth were isolated with rubberdam. An anchor clamp (N27; Hu-Friedy, Frankfurt am Main, Germany) was placed on the second molar. The whole quadrant was isolated to increase the visibility of the operative field. Adequate field isolation/sealing at the gingival margin was obtained by inversion of the rubberdam. (b) The second premolar and lower molars were prepared for non-retentive bonded ceramic onlays. The same protocol was followed for rubberdam isolation: quadrant

isolation and an anchor clamp (W8A; Hu-Friedy) was placed on the last molar. Another clamp was placed on the canine as the orthodontic retention wire did not allow complete positioning of the rubberdam at the mesial side. Floss was used to obtain good sealing at the gingival margins. The application of teflon tape at the deep subgingival margins resulted in good visibility of the cervical preparation margins. Absolute isolation is needed prior to immediate dentin sealing.

Figure 11: (a) Initial situation: a deep caries lesion was present at the distal side of the upper second premolar. (b and c) Quadrant isolation took place. The rubberdam was inverted. On the second premolar, a floss was placed to obtain a good cervical seal, as the caries was quite close to the root surface. Before starting with the cavity preparation, the operator protected the neighbour tooth with a Wedge Guard Palodent Plus (Dentsply Sirona, Konstanz, Germany). (d) Access was made to the proximal caries lesion with a small round diamond bur. (e) When entering the dentin, the caries lesion is clearly visible at the enamel-dentin junction. (f) The box was prepared with the Wedge Guard (Dentsply Sirona) into position. A fine pointed diamond bur was used to widen the box in a bucco-lingual direction. (g) After opening the box, the wedge guard was replaced by a wooden wedge to increase the visibility during cavity preparation. The wedge also protects the rubberdam and the cervical margin. Pre-wedging with a wooden wedge at this stage can result in a separation of the teeth of up to 100 μm. In this way, it is easier to obtain a tight proximal contact area during placement of the composite restoration. (h) A sharp hand excavator was used to check the dentin consistency and remove the soft carious dentin. (i) Soft dentine can easily be scooped up with a sharp hand excavator with little force being required.

Figure 11: (j) Chips of soft and leathery dentin in the cavity after using the excavator. (k) The carious dentin is firm and dry. This is the right time to use the tungsten carbide bur to remove the firm dentin. (l) The firm carious dentin was removed with a multiblade tungsten carbide bur (Komet H1-SEM) until the dentin surface was hard and clean. The bur is used dry and with low speed (7000

rpm). (m) The caries will be removed following a centripetal approach, from the periphery to the critical points in the center, this in order to prevent possible pulp exposure. (n) After removal of the caries, finishing of the cavity took place. The cervical step is finished until a straight margin is obtained with a conical shaped diamond bur with round edges (40 µm). (o) The internal angles of the cavity are rounded. Undermined enamel at the cervical step is not removed. Finishing must be done carefully in this region and the undermined enamel must be supported by a wooden wedge. (p and q) The box was opened until interproximal clearance was achieved: the buccal and lingual margin of the box are made accessible. This allows passive positioning of the matrix band, and facilitates finishing of the buccal and lingual cavity margins of the box. The sharp and irregular enamel prisms at the occlusal, buccal and lingual box margins are removed with a pointed microfine diamond bur (40 µm). This will result in improved adaptation of the composite resin at the cavity margins. (r) Tooth preparation was finalized by airborne-particle abrasion with Al_2O_3 powder (30 µm; 4 bar). (s) After air abrasion, the tooth surface to be bonded to was slightly roughened and cleaned.

Figure 11: (t) A sectioned contoured metal matrix band was positioned and fixed with a wooden wedge. The enamel margins were selectively etched with 35% phosphoric acid before application of a mild 2-step self-etch adhesive. (u) After the adhesive protocol, a layer of highly filled flowable composite was placed in the cervical third (1.5 mm) of the box and polymerized for 40 s. (v) In a next step, the marginal ridge was built up to the correct height with a conventional micro-hybrid composite. (w) After 20 s of polymerization, the matrix band was removed and the remaining occlusal cavity was restored with the same composite. (x). Final restoration 2 weeks after placement.

Figure 12: (a) Replacement of the existing amalgam restorations was required. (b) The existing amalgam restorations were removed in a minimally invasive way with a multiblade tungsten carbide bur, from the center towards the periphery. An ultrasonic device with water cooling was used to remove the last pieces of amalgam that remained to the cavity walls. Next, the existing liner was

removed with a round multiblade tungsten carbide bur at a low speed (7000 rpm). (c) The final cavity preparation is characterized by a clean and sound dental substrate, smooth transitions inside the cavity, no sharp angles, an acceptable isthmus width, and well finished cavity margins. (d) This allows the dentist to make direct composite restorations with a high hidden and perceived quality.

Figure 13: (a) Initial situation: a caries lesion was observed at the distal side of the first upper premolar. The tooth will be treated with a direct composite restoration. (b) The box was prepared until interproximal clearance was achieved: the buccal and lingual margins were made accessible. Demineralized enamel was still present at the cervical cavity margin. (c) All cavity margins were positioned in sound enamel. (d) The restored tooth immediately after placement of the class-2 composite restoration.

Figure 14: (a) After preparing a class-2 cavity on the first molar, a small caries lesion was observed at the distal side of the second premolar. As there was direct access to the lesion, the marginal ridge was preserved. The marginal ridge was not strongly undermined, and not overloaded during occlusion and articulation. (b) The mesial surface of the first molar was protected with teflon tape before restoring the proximal cavity on the premolar. (c) Application of the adhesive. (d) The composite restoration was finished before restoring the proximal cavity on the molar.

Figure 15: Bucco-lingual section of a molar with cavity preparation. (a) If the remaining cusp has a thickness of 2 mm or more, and the enamel is supported by dentin (lingual side: L), the cusp is kept. Similarly, with a cusp thickness of around 2 mm and slightly undermined enamel (on average 1 mm) (buccal side: B), the cusp can be kept if it is not heavily loaded during occlusion and articulation. (b) A strongly undermined cusp (enamel not supported by dentin) (buccal side: B) should be reduced at least 1.5 mm and capped. The more the height of the cusp is reduced, the less dentin support is

needed. This means that in the cervical area, one can end with the margin in enamel and have slightly undermined enamel.

Figure 16: The MOD cavity on the first lower molar shows strongly undermined cusps. The cusps need to be reduced 1.5 mm in order restore the fracture resistance of this tooth. This tooth was planned to be restored with a bonded indirect onlay.

Figure 17: (a) Situation before: endodontically treated molar showing a wide and deep cavity. The mesial marginal ridge was thin and a crack line was observed. To decrease excessive flexure of the high and thin surrounding walls, cusp coverage is required. Because of financial reasons, the tooth was planned to be restored with a direct composite onlay. (b) A mesial box was prepared and the cusps were reduced for 1.5 mm. The endodontic cavity was cleaned with air abrasion with Al_2O_3 powder (30 µm). (c-f) After application of a 3-step etch-and-rinse adhesive, the pulp chamber was filled with a bulk-fill fiber-reinforced composite (EverX Posterior; GC, Tokyo, Japan). (g) For the final composite build-up, a micro-hybrid composite was used. Although the final restoration did not show a completely correct tooth morphology, it was clinically acceptable. (h) The final restoration two weeks later, after rehydration of the teeth.

Figure 18: (a) Large caries lesion at the mesial side of the upper molar, after removal of the existing amalgam restoration. (b) Final cavity preparation after removal of all caries. The undermined enamel at the cervical margin was maintained. During caries removal, one must protect the undermined enamel with a wooden wedge. The caries must be removed very carefully in order not to damage the undermined enamel.

Figure 19: The internal cavity angles need to be rounded in order to decrease the stress imposed on the adhesive interface.

Figure 20: (a) Occlusal cavity before air abrasion. (b) Air abrasion with Al_2O_3 powder (50 µm) (4 bar - 10s) results in a clean and slightly roughened dental surface. It is important to air-water spray the tooth very well after air abrasion, in order to remove all the powder on the operative field. (c) Scanning electron microscopy (SEM) photomicrograph of Al_2O_3 powder (50 µm). (d-f) SEM photomicrographs of a prepared dentin surface. (d) Dentin surface prepared with a multiblade tungsten carbide bur (Komet H1 SEM); the dentin tubules are obstructed with smear. (e) Sandblasting with Al_2O_3 powder (50 µm) at an air pressure of 4 bar for 10s. The roughness of the dentin surface is increased. The smear layer is still present. At several locations, the dentin tubules were exposed. (f) After etching the sandblasted dentin surface with phosphoric acid (35%) for 15 s, the entire smear layer was removed, and dentin tubules were exposed.

Figure 21: (a) During finishing of the occlusal cavity, the sharp and irregular enamel prisms were removed with a microfine cylindric diamond bur with round angles (40 µm grit).
(b) Instruments used for removing the sharp and irregular enamel prisms in a class-2 cavity. The occlusal and proximal (buccal and lingual) cavity margins were finished with a flame shaped diamond bur (40 µm grit), used dry and with medium speed. The cervical margin of the box was finished to a straight margin with a conical shaped microfine diamond bur (40 µm grit). The sharp and irregular enamel prisms at the cervical margin were removed with a metal diamond strip.

Figure 22: (a-c) Use of sono-abrasion (Sonicflex Micro tip; Kavo Dental, Biberach/Riß, Germany) to remove the sharp irregular enamel prisms at the proximal cavity margin of a lower first molar. (a) Before finishing. (b) The smooth non-diamond coated side of the tip avoids damage to the adjacent tooth. (c) The proximal cavity shows a well finished cavity margin. (d) After removal of an inadequate filling at the distal side of the second premolar, a small caries lesion was visible at the mesial side of the first molar. (e) A hemispherical sono-abrasion tip is used for cavity preparation because of easy

access to the caries lesion. The marginal ridge was left intact. (f) Final cavity preparation after airabrasion with Al_2O_3 powder (30 µm).

Figure 23: (a) Initial situation. Old composite restorations with caries underneath need to be replaced. (b) Final cavity preparations showing a clean and sound dental substrate, smooth transitions inside the cavity, no sharp angles, removal of undermined enamel where needed, interproximal clearance in the class-2 cavity, and well-finished cavity margins. The occlusal cavity on the first upper molar was wide, but not deep and the tooth was not heavily loaded during occlusion. Therefore, the surrounding tooth structure was preserved. (c) Two weeks after placement of high-quality direct posterior composite restorations. A 3-step etch-and-rinse adhesive was used in combination a micro-hybrid composite. The composite restorations blended in very well within the surrounding natural tooth structure.

Fig. 1

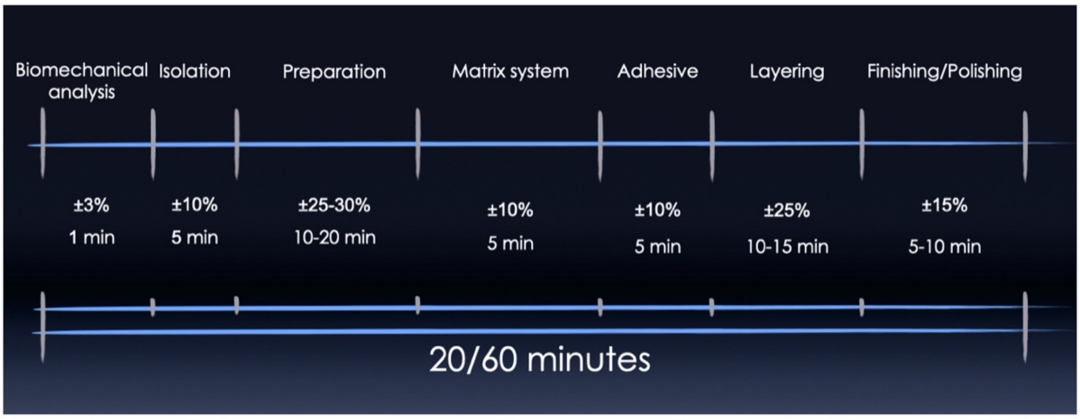

Biomechanical analysis
Isolation
Preparation
Matrix system
Adhesive
Layering
Finishing/Polishing
±3%
1 min
±10%
5 min
±25-30%
10-20 min
±10%
5 min
±10%
5 min
±25%
10-15 min
±15%
5-10 min
20/60 minutes

Fig. 2

Fig. 3

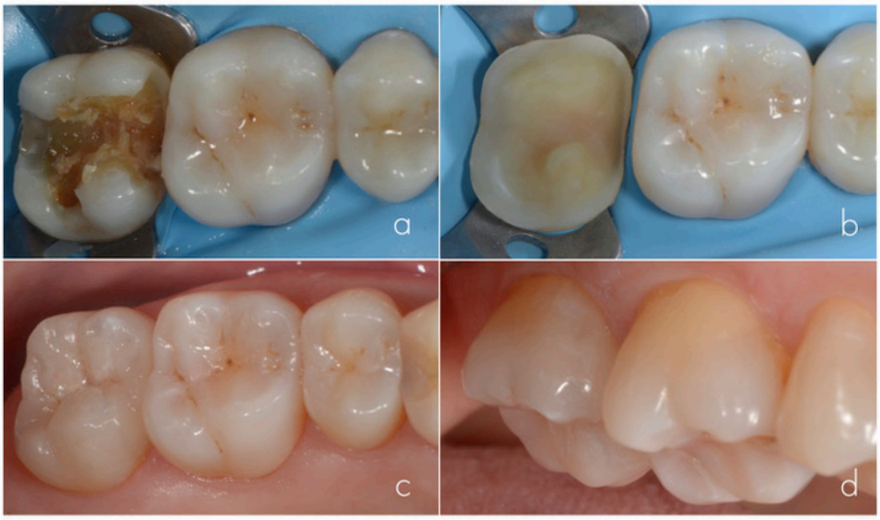


Fig. 4a-d

Fig. 5a-d

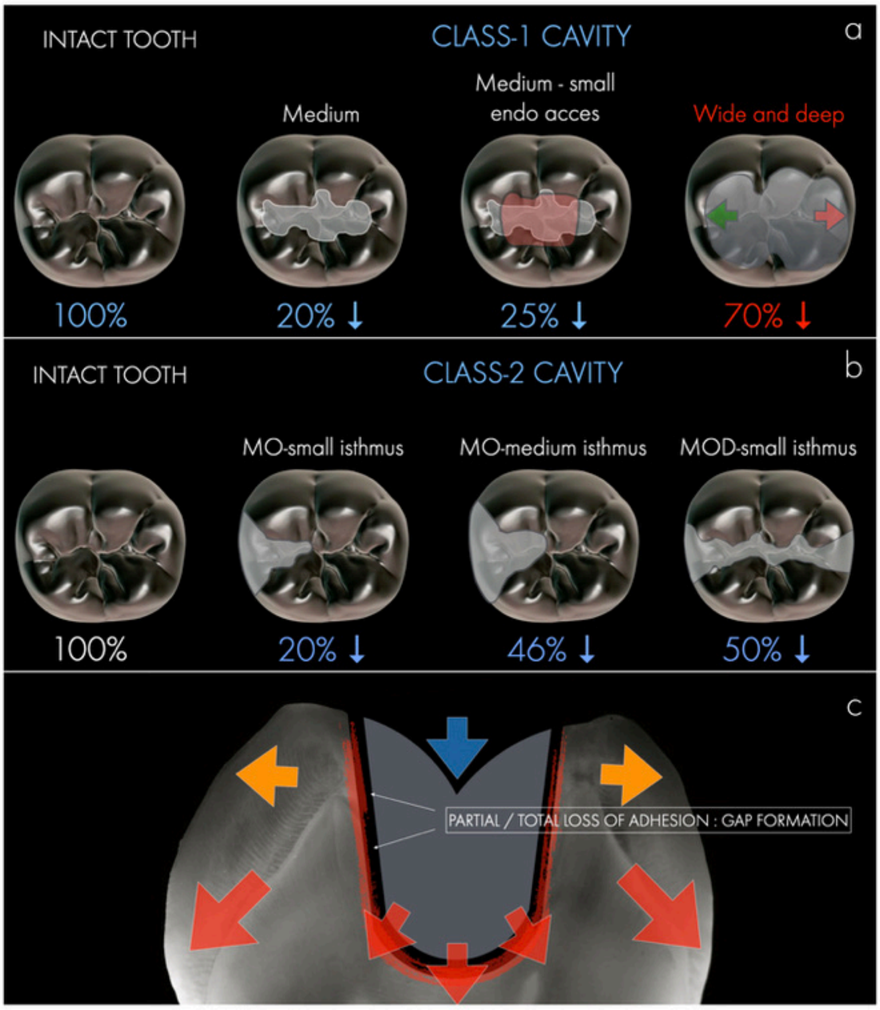

INTACT TOOTH
CLASS-1 CAVITY
a
Medium
Medium - small
endo acces
Wide and deep
100%
20%
25%
70%
INTACT TOOTH
CLASS-2 CAVITY
b
MO-small isthmus
MO-medium isthmus
MOD-small isthmus
100%
20%
46%
50%
c
PARTIAL / TOTAL LOSS OF ADHESION : GAP FORMATION

Fig. 6a-c

Fig. 7a-c

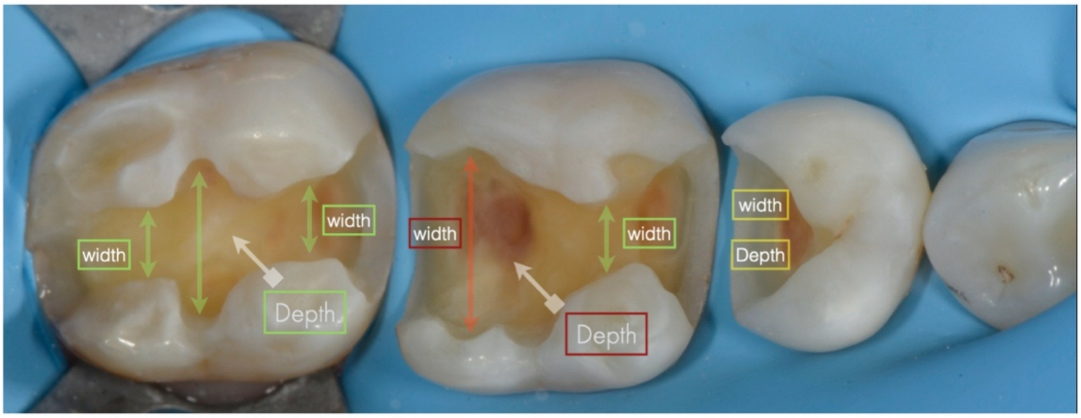


Fig. 8

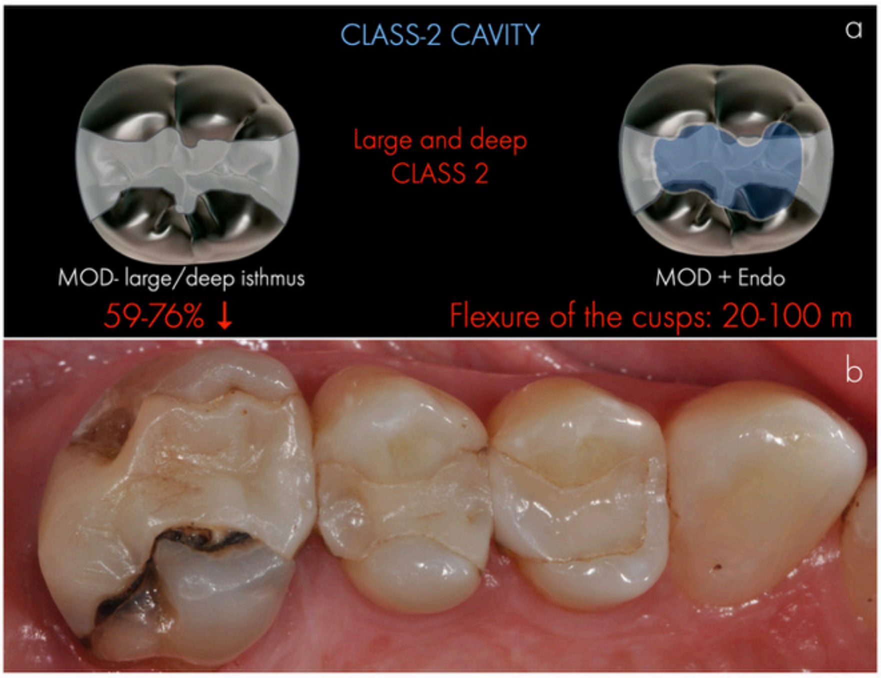

CLASS-2 CAVITY
a
Large and deep
CLASS 2
MOD- large/deep isthmus
59-76% ↓
MOD + Endo
Flexure of the cusps: 20-100 m
b

Fig. 9a-b

Fig. 10a-b

Fig. 11a-i

Fig. 11j-s

Fig. 11t-x

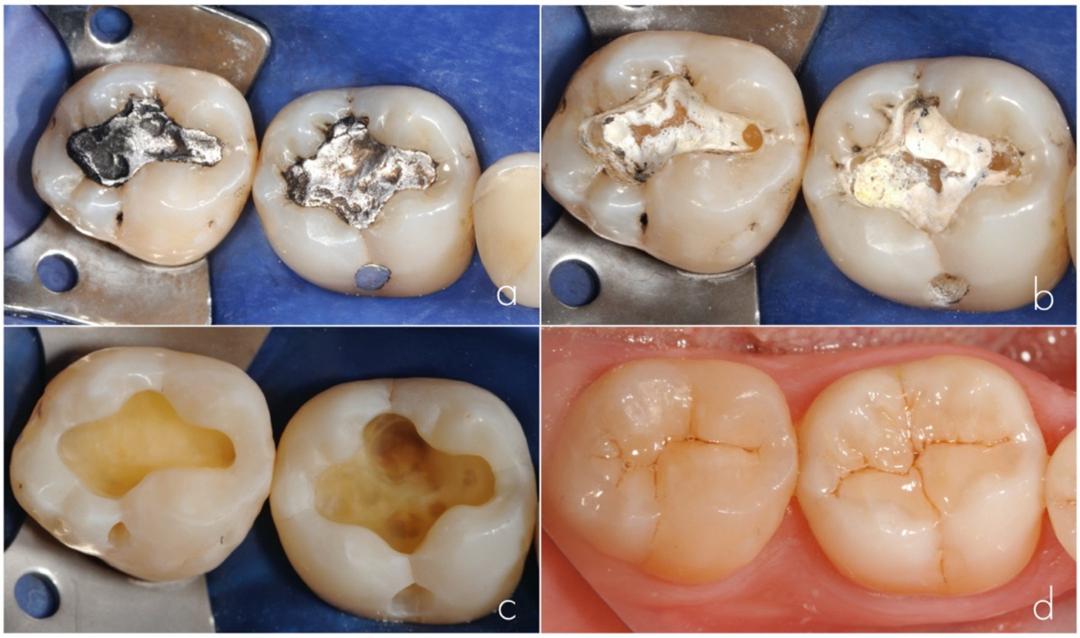


Fig. 12a-d

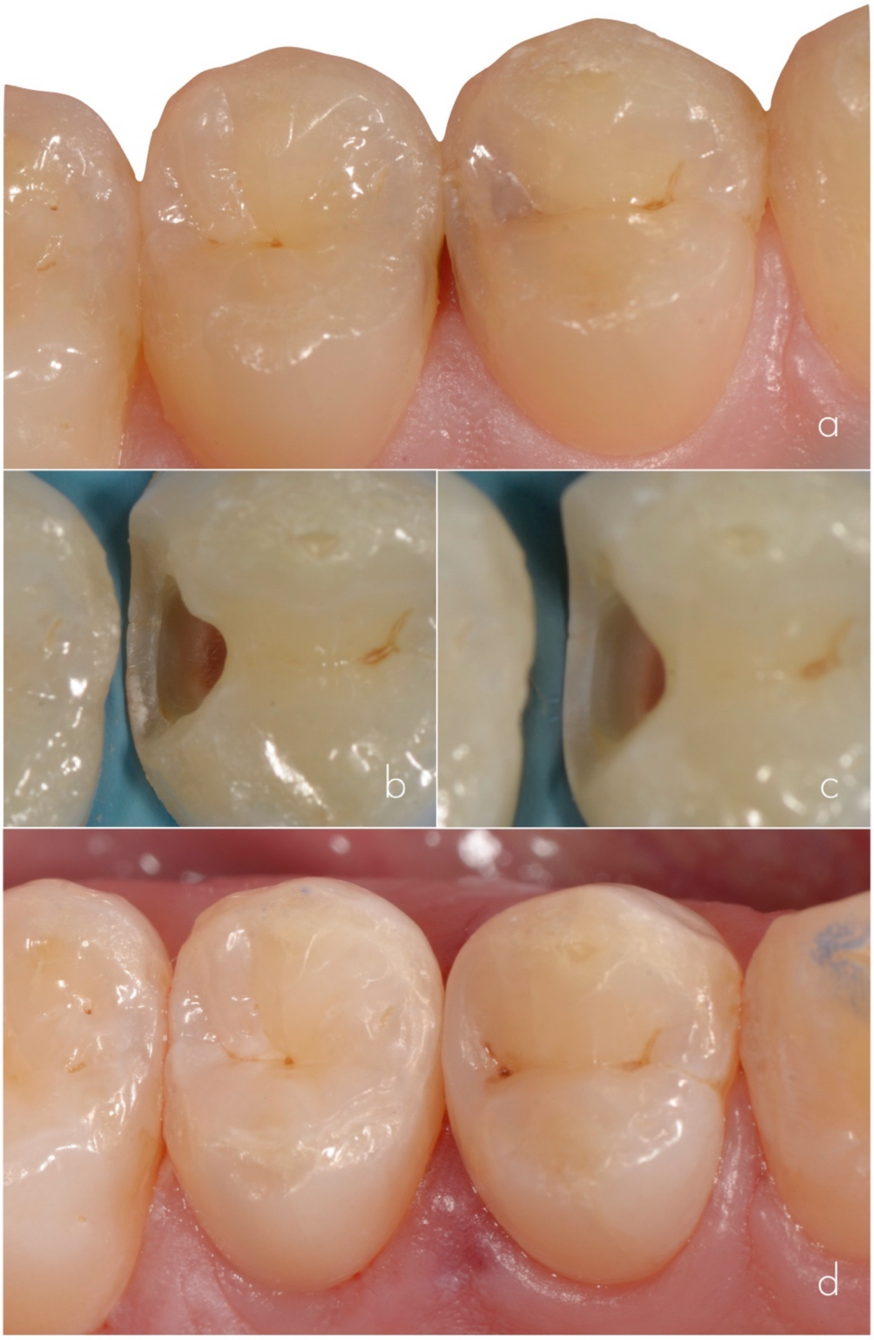


Fig. 13a-d

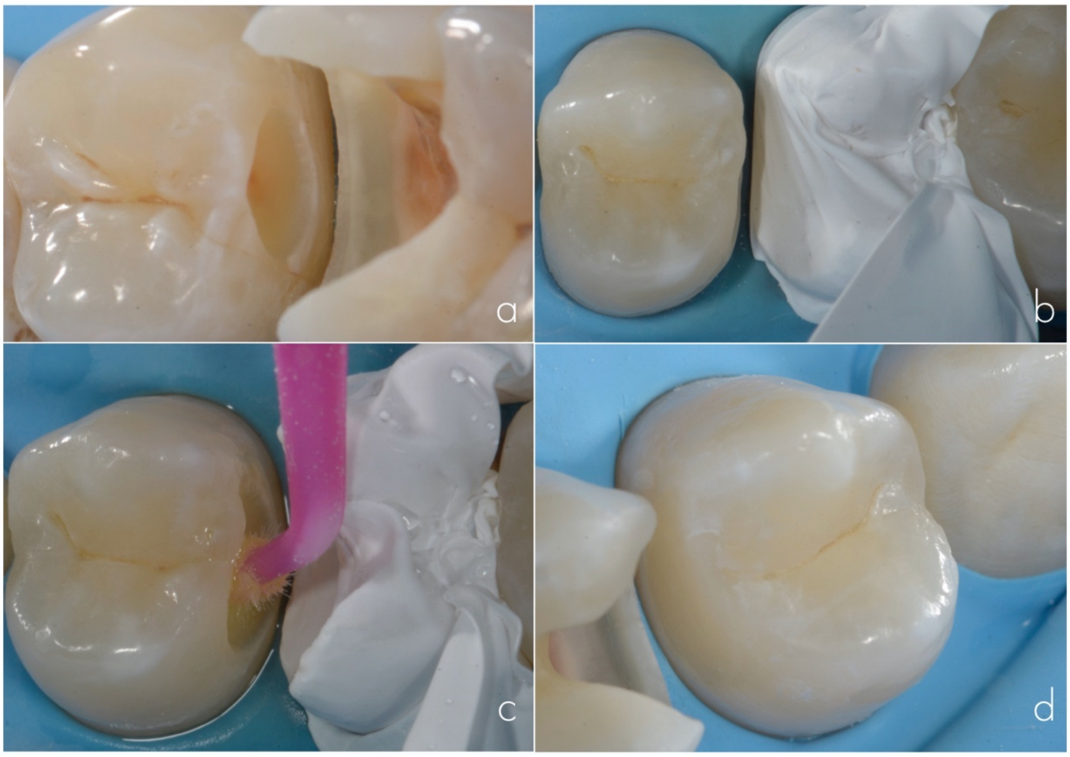
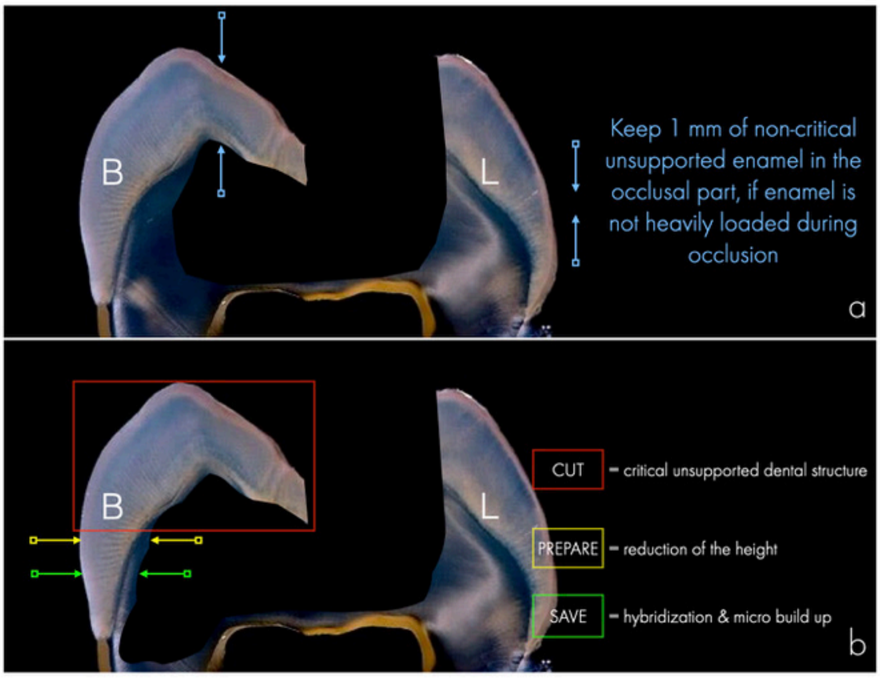


Fig. 14a-d



B
L
Keep 1 mm of non-critical unsupported enamel in the occlusal part, if enamel is not heavily loaded during occlusion
a
B
L
CUT = critical unsupported dental structure
PREPARE = reduction of the height
SAVE = hybridization & micro build up
b

Fig. 15a-b

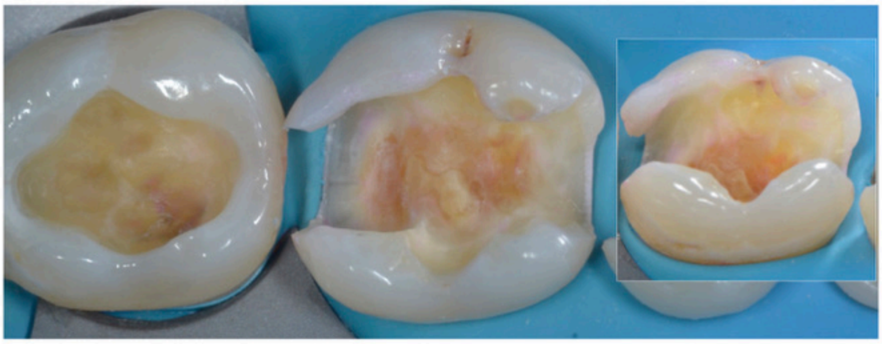


Fig. 16

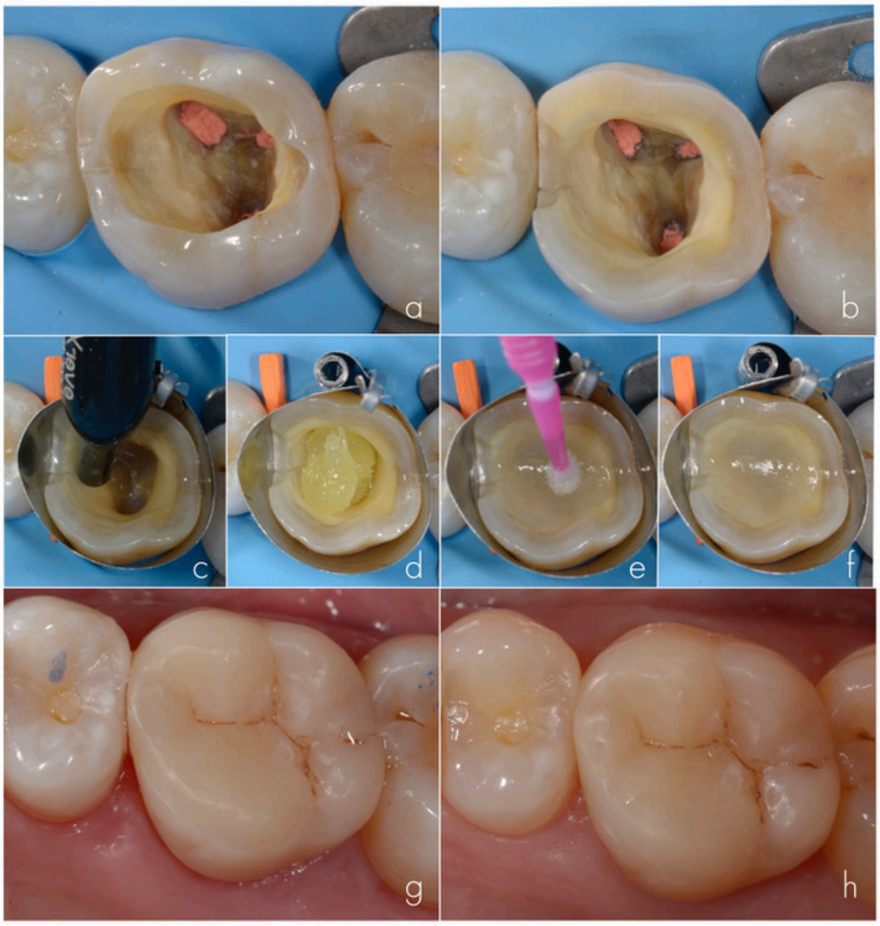


Fig. 17a-h

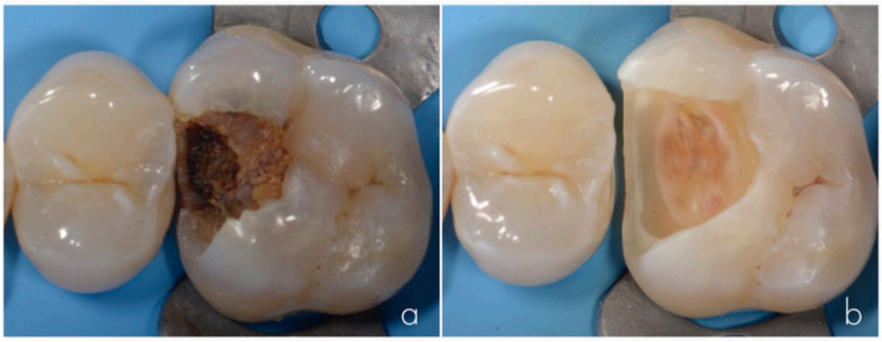


Fig. 18a-b

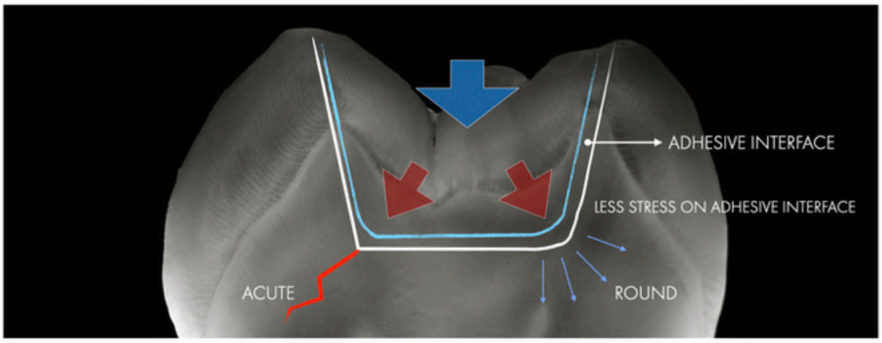
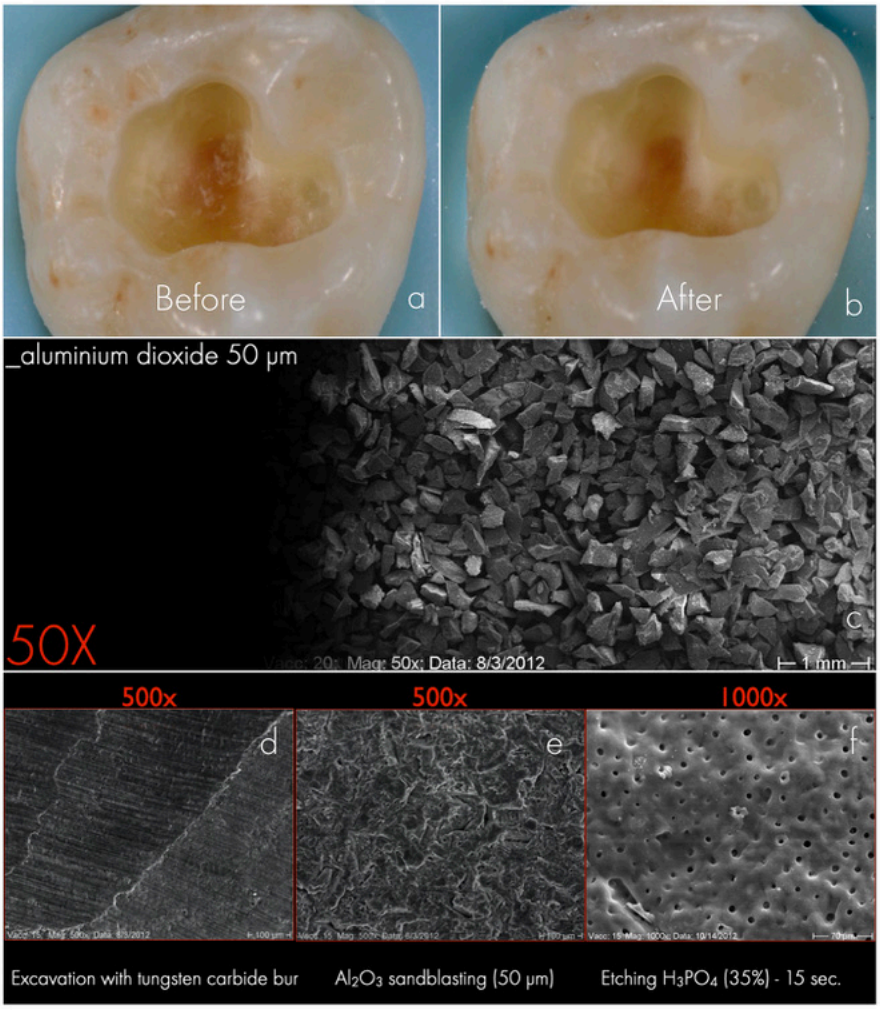

ADHESIVE INTERFACE
LESS STRESS ON ADHESIVE INTERFACE
ACUTE
ROUND

Fig. 19



Before
a
After
b
_aluminium dioxide 50 µm
50X
c
Vacc: 20; Mag: 50x; Data: 8/3/2012
1 mm
500x
500x
1000x
d
e
f
Excavation with tungsten carbide bur
Al_2O_3 sandblasting (50 µm)
Etching H_3PO_4 (35%) - 15 sec.

Fig. 20a-f

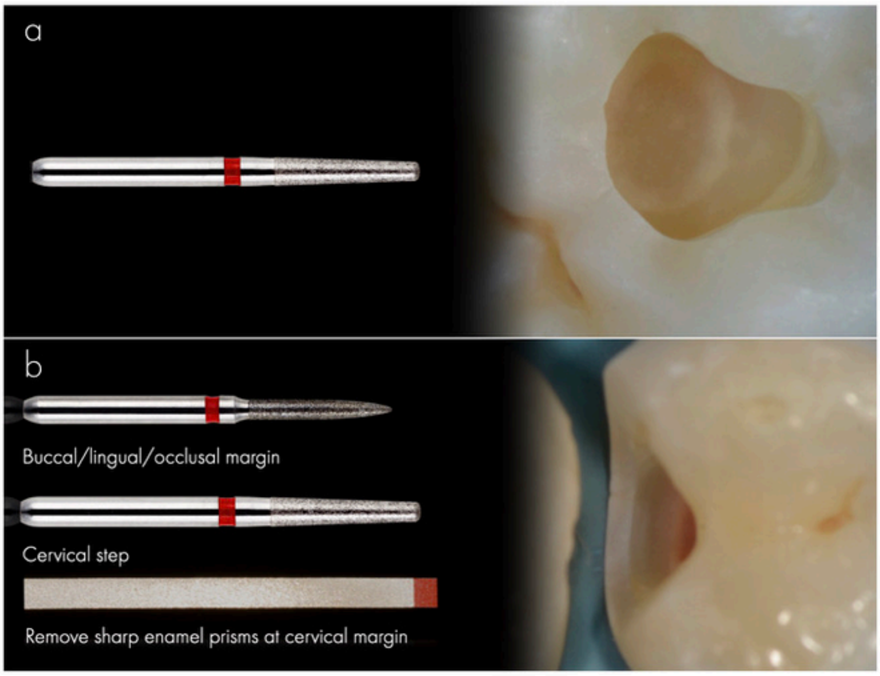

a
b
Buccal/lingual/occlusal margin
Cervical step
Remove sharp enamel prisms at cervical margin

Fig. 21a-b

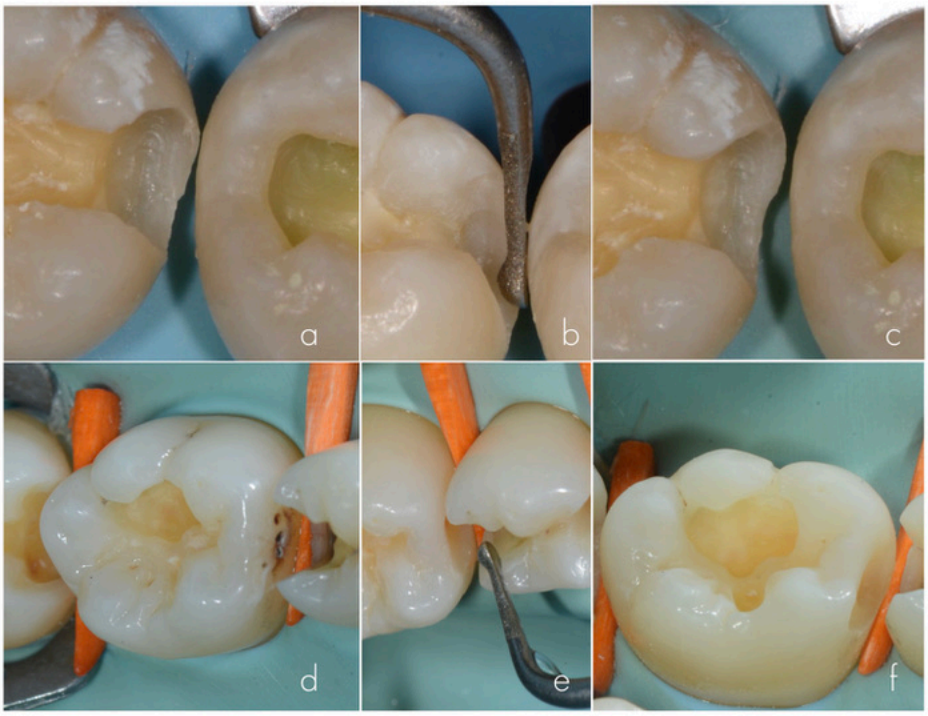


Fig. 22a-f

Fig. 23a-c