Resins and Porcelain

Composite Resins and Bonded Porcelain: The Postamalgam Era?

Pascal Magne, DMD, PhD

Abstract

The growing demand of patients for esthetic or metal-free restorations, together with the ongoing interest of the dental profession for tissue-preserving materials have led to the actual development of posterior adhesive restorations. It is now clearly established that a new biomimetic approach to restorative dentistry is possible through the structured use of "tooth-like" restorative materials (composite resins and porcelain) and the generation of a hard tissue bond (enamel and dentin bonding). Scientific studies and clinical experience have validated use of bonded tooth-colored restorations, and we may have entered the so-called "postamalgam era."

These significant changes have already impacted daily general practice, including pediatric dentists in California, but it is now critical to assure that the corresponding evidence-based process is integrated to the predoctoral programs statewide and nationwide. This paper reviews the foundations of this evolution, based on maximum tissue preservation and sound biomechanics, the so-called "biomimetic principle." Using scientific evidence and clinical experience, a model for the adequate use of current restorative systems is presented. This work, illustrated with cases with up to 10 and 14 years' follow-up, sets the ground rules for the clinical performance of the posterior esthetic restoration. Important considerations about tooth preparation, matrix techniques, layering methods, immediate dentin sealing and base lining are presented.

It is common knowledge that patients' requests and clinicians' interest in esthetic restorations are not limited to anterior teeth. As a result, posterior tooth-colored adhesive restorative techniques have grown considerably over the last decade. It was clearly established that a new biomimetic approach to restorative dentistry was possible through the structured use of "tooth-like" restorative materials (composite resins and porcelain) and the generation of a hard tissue bond (enamel and dentin bonding).[1] Scientific studies and clinical experience have validated use of bonded tooth-colored restorations (see Section 3.) and we may have entered the so-called postamalgam era.[2] The changes toward esthetic and adhesive dentistry have largely impacted daily clinical practice,

Author / Pascal Magne, DMD, PhD, is associate professor with tenure, chair of Esthetic Dentistry, Division of Primary Oral Health Care, University of Southern California School of Dentistry.

and it is now critical to assure that the corresponding evidence-based process is integrated to the predoctoral programs statewide and nationwide. Educators, both in the academic arena and in the lecture circuit, hold the responsibility to provide the most contemporary oral health care level in restorative dentistry based on maximum tissue preservation and sound biomechanical principles. It will be explained why these goals cannot be achieved with traditional materials and techniques. A number of European schools have abandoned the teaching of amalgam or are in the process of achieving that goal.[3,4] Pediatric dentistry is not excluded from this phenomenon.[5] There are numerous reasons for this change.

From an academic perspective, shifting from amalgam to tooth-colored materials in teaching the restoration of posterior teeth may be found to have a considerable enriching effect on the dental curriculum, mainly due to tissue preservation and the biomechanical principles that will be discussed in Section 1.[3] As stated by Roeters et al., the introduction of resin composites is not just a change in materials and techniques but also a change in treatment philosophy.[4] The reduced need for preparation and the strengthening effect on the remaining tooth were the principal reasons for the shift from dental amalgam to adhesive dentistry with resin composite at Nijmegen dental school. The same philosophy inspired curricular changes in the dental schools at University of Zurich and Geneva, where this shift also started 20 and 15 years ago, respectively.

It can be questioned whether these changes will affect some specific area of restorative dentistry such as pediatric dentistry during community service to the underserved population, where amalgam is considered most adequate because of its simplicity of use. It appears

that the benefits of adhesive tooth-colored materials apply also to primary molars, more conservative preparations can be performed maintaining more tooth structure.[6,7] Simplified adhesive protocols have also been proposed, as for instance the use of glass ionomer cements and in particular the resin-modified types, which possess proper-

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ties that make them almost ideal for pediatric dentistry. Data indicates that resin-based composite and resin-modified glass ionomer serve very well in pediatric dentistry and are considered the material of choice by 40 percent of California pediatric dentists.[8,9]

The core material presented in this article is a summary of an evidence-based staged process taking place at the predoctoral level (section restorative dentistry) at the USC School of Dentistry. A small group of full-time faculty (Faculty Esthetic Update group) was created and led by the author to:

■ Analyze the available literature,

■ Develop a structured hands-on experience,

■ Design and construct a manual for posterior esthetic restorations, and

■ Calibrate the rest of the faculty based on these new curricular changes.

The article will review the data currently available to support the transi-

tion from the amalgam era to the new "biomimetic" era in restorative dentistry, and will also review data to help the clinician choose between composite resin and ceramics for posterior bonded restorations. Essential clinical steps to best use these two different materials will also be illustrated.

Section 1. Composite Resins and Ceramics According to the Biomimetic Principle

Biomimetics is a concept of medical research that involves the investigation of both structures and physical functions of biological "composites" and the designing of new and improved substitutes. In dental medicine, the term "biomimetics" is a useful word with increasing popularity. The primary meaning refers to material processing in a manner similar to the oral cavity such as the calcification of a soft tissue precursor. The secondary meaning of biomimetics refers to the mimicking or recovery of the biomechanics of the original tooth by the restoration. This of course is the goal of restorative dentistry. The benefit of biomimetics, when extended to a macrostructural level, can trigger innovative principles in restorative dentistry.

Restoring or mimicking the biomechanical, structural, and esthetic integrity of teeth constitutes the driving force of this process. Physiological performance of intact teeth is the result of an intimate and balanced relationship between biological, mechanical, functional, and esthetic parameters.[1]

Natural teeth, through the optimal combination of enamel and dentin, constitute the perfect and unmatched compromise between stiffness, strength, and resilience. Restorative procedures and alterations in the structural integrity of teeth can easily violate this subtle balance. Another alteration is represented by the age-related changes of the dentition, which constituted the main challenge

Physical properties of dental hard tissues and corresponding biomaterials

	Elastic modulus (GPa)	Thermal expansion coefficient (X10^{-6}/°C)	Ultimate tensile strength (MPa)		Corresp. material	Elastic modulus	Thermal expansion coefficient	Ultimate tensile strength
Enamel	~80[1]	~17[2]	~10[3]	→	Feldspathic ceramics	~60-70[4]	~13-16[5]	~25-40[6]
Dentin	~14[7]	~11[2]	~44-105[7,8]	→	Hybrid composites	~10-20[9]	~20-40[10]	~40-60[11]

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of modern dentistry, facing a population that is clearly aging and at the same time, retaining more of its natural teeth. Restorative procedures and aging can make the tooth crown more deformable, and the tooth can be strengthened by increasing its resistance to crown deformation. When a more flexible material replaces the enamel shell, one can expect only partial recovery of crown rigidity. From a biomechanical perspective, composite resins are more "dentin-like" while porcelain is the most "enamel-like" material (**Table 1**).

The Biomimetic Principle in Restorative Dentistry

The intact tooth in its ideal hues and shades, and perhaps more importantly in its intracoronal anatomy, mechanics and location in the arch, is the guide to reconstruction and the determinant of success. The approach is basically conservative and biologically sound. This is in sharp contrast to the porcelain-fused-to-metal technique, in which the metal casting with its high elastic modulus makes the underlying dentin hypofunctional. The goal of biomimetics in restorative dentistry is to return all of the prepared dental tissues to full function by the creation of a hard tissue bond that allows functional stresses to pass through the tooth, drawing the entire crown into the final functional biologic and esthetic result. The goal of adhesive restorative techniques is the maximum preservation of sound tooth structure and the maintenance of the vitality of the teeth to be restored. From a biomechanics standpoint (**Table 1**), moderate alterations of teeth should be treated with composite resins. Bonded porcelain restorations are recommended to treat the most perilous situations (worn, non-vital, or fractured teeth) thus avoiding the use of intraradicular posts or full-coverage crowns. This results in considerable improvements, comprising both the medical-biological aspect and the socioeconomical context (i.e. decrease of costs when compared to traditional and more invasive prosthetic treatments).

Major advances have resulted from the study and understanding of cuspal flexure and plastic yielding, which represent key parameters in the performance of the tooth-restorative complex.[10,11] Subclinical cuspal micro-deformation, i.e. below the threshold of chairside observation, has been identified since the early 1980s by Morin et al.; and it is now well accepted that intact posterior

Figure 1. Typical crack developing under an existing MOD amalgam restoration due to the absence of cusp stabilization. There was no decay but significant pain to hot/cold air or fluids, and biting.

Figure 2a.

Figure 2b.

Figure 2c.

Figure 2d.

Figure 2. Examples of clinical follow-ups of OB direct composites at four years (a) and MOD at seven years (b), an OD intraoral composite inlay at 10 years (c), and an MOD extraoral semi-direct composite inlay at 14 years (d).

teeth demonstrate cuspal flexure due to their morphology and occlusion.[12,13] Restorative procedures can increase cuspal movement under occlusal load, which in turn may result in altered strength, fatigue fracture, and cracked tooth syndromes.[14-17] Amalgam restorations are the most typical example of this phenomenon (**Figure 1**). Such knowledge allowed considerable development of methods improving fracture resistance of teeth through various forms of full or partial coverage and, more recently, through the use of conservative adhesive techniques (**Figure 2**).[18-24]

Section 2. Composite Resins and Ceramics According to the Restorative Technique

There are numerous treatment modalities allowing the placement of esthetic adhesive restorations in posterior teeth (**Table 2**): The direct technique, meaning that all restorative steps are accomplished intraorally, during a single appointment; the semi-direct technique also requires a single appointment but differs from the direct one by a number of extraoral steps. The semi-direct restoration is finally luted, as is the case with the indirect technique, which implies at the very least, two appointments and the collaboration of a dental laboratory. Only direct and semi-direct restorations are made entirely chairside.

Composite semi-direct restorations can be fabricated intraorally after cavity insulation, or extraorally on a fast-setting model (usually silicone) made from a synthetic elastomer or alginate impression.[25] After fabricating the restoration, it is recommended to submit it to a thermic or photo-thermic process (postpolymerization) in a small furnace before cementation. The postpolymerization was supposed to improve the material's physico-chemical properties. In fact, the main benefits of this treatment are improved wear resistance and dimensional stability of the material.[26,27] Marginal adaptation and seal are potentially better as polymerization shrinkage is confined to the sole luting composite layer.[28,29] Practically, extraoral fabrication of the restoration on the model is a substantial advantage over direct and semi-direct intraoral techniques. However, supplemental

procedures are required to make such extraoral restorations and these increase the time needed for fabrication as well as the related treatment fees.

Laboratory composites with improved strength and wear resistance are now commercially available and are increasing in popularity. Coupled with improvements in resin-based luting cements and dentin-bonding systems, indirect composite restorations may be considered appropriate for single-unit inlays or onlays. Laboratory made or semi-direct composites are generally preferred to porcelain restorations for inlays, due to their excellent aesthetic result and being less expensive for the patient (unless indirect pressable ceramics are used). Composite restorations also may demonstrate less abrasion to the opposing dentition than porcelain restorations.

There are several semi-direct systems that can produce a milled ceram-

Table 2

Classification and recommendations for adhesive restorative techniques in posterior teeth

Direct technique (chairside) – composite resins

Recommended for preventive as well as conservative Class I cavities and small to medium Class II restorations. Applied in 1.5-2.0 mm increments. Metal matrix preferred, as it is believed to improve polymerization by light reflection.

Semi-direct technique (chairside) – composite resins or ceramics

Recommended when direct techniques are inappropriate due to composite shrinkage (large volume) and indirect technique costs are not justified. Indicated for large Class I and II preparations involving a limited number of teeth. Thought to be best for premolars and first molars with favorable mouth access.

Intraoral composite inlays — Bulk or layered build up and light polymerization in vivo. Complete conversion accomplished via photo-thermic postcuring. Composite materials recommended are the same used for direct application.

CAD/CAM inlays — Currently limited to CEREC technology. Recommended for Class I and II composite and porcelain restorations of larger size in molars. Technique-sensitive relative to powdering and optical impression. Significant long-term data are available about these types of restorations.

Extraoral composite inlays/onlays — Recommended for improved esthetics and morphology of composite restorations as it allows more sophisticated layering techniques. Can be used for moderate to large-size cavity preparations with or without ideal access. A fast-setting silicone model material is required for this technique (e.g., Mach2 and Blue Mousse by Parkell).

Indirect techniques – composite resins or ceramics

Recommended for *serial* restorations when esthetics and dynamic occlusion issues are of primary concern.

Indirect composite inlays — Recommended for *serial* restorations *without* cusp coverage or with *limited cuspal coverage* leaving at least one functional cusp. Should be avoided for large areas of occlusion or stress.

Indirect ceramic inlays/onlays/overlays — Laboratory processed restorations best indicated for larger *serial* restorations that *include* cusp coverage. Most long-term data involves these types of restorations.

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ic restoration: The CAD-CAM and the "pantograph" systems. The costs of CAD-CAM systems are high and the resulting restorations yield limited esthetic results when compared with other restorative techniques. The well-known CEREC system (Sirona, Charlotte, N.C.) is undoubtedly the most practical and integrated system. It represents a concrete contribution of new technologies to the dental profession and it probably reflects the future of restorative dentistry. The CELAY pantograph (Mikrona, Spreitenbach, Switzerland) is a totally computer-free system that allows the replication of an intraorally made resin inlay into a ceramic inlay. This replication consists in the milling of a ceramic block by burs and discs directed by the move-ment of similar form guides touching the resin inlay. The main disadvantage of the CEREC and CELAY systems is the cutting (subtractive process) of occlusal anatomy inside the ceramic or resin. This procedure generally results in a simplified morphology. An additional cosmetic firing may improve the final esthetics.

There are several types of ceramic materials used to fabricate posterior restorations in the laboratory, among others:

Traditional feldspathic porcelain is one of mostly frequently used materials to fabricate the posterior porcelain restorations. When combined with hydrofluoric acid etching and silanization, they show extremely reliable bonding to resin. Both refractory die and platinum foil techniques could be used to fabricate the restoration. Excellent esthetic, marginal fit, and function can be achieved with feldspathic porcelain restorations.

Pressed ceramic (e.g. Authentic, Microstar, Lawrenceville, Ga.; Empress, Ivoclar Vivadent, Amherst, N.Y.) offers two elaboration modalities: the reinforced pressed porcelain is used to fabricate either an entire restoration or only a core. This latter option allows esthetic improvements and characterization by additional ceramic firing. Although esthetic characterization remains limited compared to the full-thickness layering than can be applied with the refractory die technique, pressed ceramics may offer the best esthetics/economics ratio of all techniques for posterior indirect porcelain restorations.

Slip casting (In-Ceram Spinell, Vita Zahnfabrik, Bad Säckingen, Deutschland) can generate restorations with higher intrinsic strength compared to other systems. The basic method was originally marketed for full crowns and later adapted to bonded porcelain restorations with the use of spinel ($MgAl_2O_4$) instead of alumina. Due to the high crystalline content of this material, traditional hydrofluoric acid etching is not effective. Resin bonding to In-Ceram alumina, for instance, requires tribochemical silica coating or use of a special resin monomer.

Machined ceramics (e.g. Cerec InLab, Sirona; CELAY, Mikrona) even though originally designed for chairside use, have also become popular for laboratory use. Bonded porcelain restorations made from machined ceramic suffer from shade uniformity and rather simplistic anatomy, unless additional porcelain firings are carried out.

Section 3. Composite vs. Ceramics According to In Vitro and In Vivo Studies

Using simulated chewing fatigue, indirect composite and ceramic inlays seem to perform very similarly, with a slight advantage for ceramic restoration with regard to their adaptation to dentin, their marginal adaptation and their ability to stabilize the cusps.[30-32] Some of these differences might very well be become clinically insignificant with the advent of immediate dentin sealing (see Section 6). In vivo, indirect composite and ceramic inlays seem to perform very similarly on vital teeth and ceramic inlays tend to show better results for anatomic form and restoration integrity.[33] Barghi and Berry demonstrated 100 percent success with porcelain overlays at four years despite the fact that they did not use immediate dentin sealing.[34] The porcelain overlay seems to be a very promising restoration in term of mechanical resistance and stress distribution as demonstrated by Magne and Belser.[35] Cerec inlays have the best overall survival rate (89 percent at 10 years) and their annual failure rate is comparable to gold restorations.[2,36]

Considering the mean annual failure rates in posterior stress-bearing cavities, amalgam systematically exceeds adhesive restoration: 3.0 percent for amalgam restorations; 2.2 percent for direct composites; 2.9 percent for composite inlays; 1.9 percent for ceramic

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Interestingly, premolars systematically perform better than molars regardless of the restorative materials used.

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restorations; 1.7 percent for CAD/CAM ceramic restorations; and 1.4 percent for cast gold inlays and onlays.[2]

Respect for correct indications of the different techniques (direct or luted), following established protocols, and enough time for education (learning curve) will ultimately result in excellent survival rates for esthetic adhesive restorations. From the previously mentioned studies, one also understands that the main complication with esthetic adhesive restoration is not secondary caries but fracture. Postcuring composite inlays, which has been demonstrated to improve mechanical properties in vitro and ensure the dimensional stability of inlays/onlays at the time of placement (see Section 5), does not seem to improve clinical performance. Interestingly, premolars systematically perform better than molars regardless of the restorative materials used. In small-to-medium size cavities (**Figure 2**), there is little difference in the behavior of direct vs. indirect and composite vs. porcelain restorations. There is still need to evaluate this possible difference in large restorations and cusp coverages. In the absence of additional evidence, use of porcelain should be favored in cusp coverages, overlays and all types of restorations in nonvital teeth.

Section 4. Clinical Considerations About Direct Composites

Beyond the choice of the restorative material itself, there are significant clinical considerations that will influence the performance of the restoration. Sections 4, 5, and 6 will review essential elements related to tooth preparation, restorative techniques and instrumentation, as well as practical elements for the optimal use of composite resins and ceramics.

Tooth preparation. Outline form of the preparation initially depends on the extent of the caries, demineralization of adjacent enamel, discoloration of enamel or dentin that might have a negative effect on esthetics and the geometry of the restoration to be replaced. When preparing a tooth in the perspective of an adhesive restoration, the principle of maximum tissue preservation has to be respected. This implies that certain structures such as marginal ridges, oblique ridges, and sound occlusal surfaces have to be preserved, even where enamel is not fully supported by dentin. For adhesive direct restorations, the conventional geometry of G.V. Black cavities is not optimal. Lutz et al. described the "adhesive preparation" consisting of a

conservative round or ovoid proximal box and occlusal extensions, including beveling of enamel margins.[37] For metallic restoration replacement, the general cavity design is already determined and the preparation has to be completed by the beveling of enamel margins after removal of any damaged tissues. This is commonly known as a "beveled conventional preparation." Preparations for composite resins can be shallower and the occlusal outline narrower than for amalgam.[38] Etched enamel rods on a beveled margin produce a better bonding surface due to the diagonally sectioned enamel rods, which can be etched more effectively. Therefore, enamel in the proximal wall (especially slot preparations Class II cavities) should have a 45-degree bevel because prism direction is at right angles to the cavosurface.[39] Occlusal bevels are deemed unnecessary because the prism direction in the zone of the central fossa is inclined toward the fossa. By preparing the occlusal section of the cavity with parallel walls (or slight convergence), the diagonal cut across the prism's long axis thereby achieves more efficient etching. At the end of two years, no differences between beveled and nonbeveled occulsal margins could be detected in color, microleakage, caries, wear, or marginal adaptation.[40] However, smoothing of the occlusal margins by finishing with a fine diamond bur is recommended to remove possible weakened enamel and to make the margin less visible when the restoration is completed. Extensions of proximal walls are determined by the caries, existing restoration, decalcification, or discoloration in esthetic areas. The extensions are kept as minimal as possible and can be placed in contact areas.

Oscillating technology for shaping and beveling. The sole use of rotary instruments was demonstrated to be responsible for considerable iatrogenic damage to adjacent teeth. The use of safe-sided oscillating diamond tips (SonicSys, KaVo, Lake Zurich, Ill.) on an air scaler (e.g. Brasseler/NSK AS2000, Savannah, Ga., or SonicFlex 2000N, KaVo) for shaping and finishing the proximal and proximal-gingival wall can significantly reduce damage to the adjacent dentition (**Figure 3**) and soft tissues.[41-43] The air-scaler handpiece vibrates at a frequency of 6000-6500 Hz (max 3.5 bar). Five

> At the end of two years, no differences between beveled and nonbeveled occulsal margins could be detected in color, microleakage, caries, wear, or marginal adaptation.

different tips with a 40 micron medium grit (SonicSys/SonicFlex, KaVo) are used at pressure <2N.

Matrix techniques. Controlling contacts and contours of direct composite restorations may prove difficult and is not dependent on the type of restorative material used (regular vs. packable). Contoured metal bands and special rings (e.g. Palodent/Bitine ring, Danville, San Ramon, Calif., or Composi-Tight, Garisson Dental Solutions, Springlake, Mich.) significantly help in obtaining adequate contact tightness (**Figure 4**).[44] When used properly, good proximal contact can be achieve consistently and predictably. In addition, the use of a metallic matrix improves polymerization by light reflection.[45]

The C-factor. The setting stress in composite resins was studied as a function of restoration shape. The shape is described by the configuration factor, C, the ratio of the restoration's bonded to unbonded (free) surfaces.[46] In the case of direct composite restorations, it was shown that in most of the clinically relevant cavity configurations (high C-factor), the shrinkage stress-relieving flow is not sufficient to preserve adhesion to dentin by dentin-bonding agents. Increased C-factor will also negatively impact the flexural strength and elastic modulus of the restorative material.[47] The above mentioned elements call for the use of techniques that might reduce C factor effects (sectioning, incremental build-up) and delay the gel point (slow-start or pulse-delay polymerization).

Layering techniques. There are many different direct filling techniques, including simple ones, like the "bulk" restoration, and more sophisticated ones, like the "three-sited light-curing technique."[48] The challenge of direct composites is that the placement technique has to compensate for the unavoidable composite polymerization shrinkage, especially for Class II and larger Class I preparations. Shrinkage stresses negatively influence the mechanical properties and marginal integrity of the restorative material.[47] To that effect, numerous procedures have been proposed: segmentation of the polymerization by multilayer techniques (horizontal, three-sited, oblique), use of condensation and polymerization tips, or placement of glass inserts to reduce the volume of the shrinking material, and more recently, the use of soft-start polymerization.[49-53] The very simple horizontal layering technique along with the use of a filled three-step etch and rinse adhesive (Optibond FL) can be recommended as it proved to be efficient in maintaining high bond strength to dentin.[54] A perfect

Figure 3. Oscillating hemispherical tip (No. 32, KaVo) is used to shape and finish the proximal aspect of the preparation for a direct composite. The polished nonworking side of the tip can be guided by the intact adjacent tooth surface (arrows). Along with other tip shapes, these instruments allow the perfect designing of different butt, chamfer or bevel margin finish line with no risks for iatrogenic damage to the adjacent dentition.

Figure 4. Example of sectional metal bands with separation ring (Composi-Tight Gold, Garisson Dental Solutions) to secure contact points with direct composite restorations.

gingival seal and adaptation of direct composite resin restoration cannot predictably be obtained despite the use of the aforementioned placement techniques. However, the clinical relevance of this imperfect seal is not known. It should, however, be pointed out that polymerization shrinkage can be only partially compensated, which led to the development of semi-direct and indirect techniques for larger restorations. The use of opaque and warm shades at the bottom to translucent and lighter shades at the top and the application of intensive coloring resins either on the restoration surface or preferably under the last composite layer can result in more natural appearing restorations (**Figure 5**).[55]

Section 5. Clinical Considerations Regarding Semi-Direct Techniques

Large Class I and II cavities cannot be adequately restored using a direct technique. The early development of semi-direct techniques, was justified by the necessity to reduce the contraction shrinkage and consequently to improve marginal adaptation and seal.[56,57] As with direct restorations, semi-direct techniques are mainly advocated to

restore a limited number of teeth. When the teeth can adequately be accessed, large Class I and Class II cavities can be restored with either intraoral composite inlays or with CEREC (Sirona) or CELAY (Mikrona) ceramic inlays. These specific semi-direct systems require crucial intraoral steps and are therefore more suitable for bicuspids and first molars. Principles for tooth preparation of semi-direct restorations are essentially the same as those used for indirect restorations (see Section 6).

Intraoral composite inlays. The inlay is made by placing one or two composite increments inside the isolated cavity. After intraoral polymerization, the inlay can be removed provided that the cavity has been properly tapered and isolated. The inlay can be additionally subjected to a photothermic treatment (post-polymerization process). This additional procedure results in the inlay reaching the optimal resin conversion rate in a few minutes, ensuring dimensional stability and maximal hardness of the composite material. A 10-year follow-up view of an intraoral inlay is featured in **Figure 2c**. Intraoral inlays are not currently used at USC School of Dentistry for two reasons:

■ MOD cavities or cavities with a complex geometry may be problematic because of the mesio-distal shrinkage component, which tends to lock the inlay into the prepared tooth.

■ The application of optimized dentin bonding involves a technique called immediate dentin sealing (see Section 6), which also tends to lock the inlay into the prepared tooth because of the adhesion to the sealed dentin.

Cerec/Celay. The CAD-CAM CEREC system (Sirona) utilizes an optical impression of the preparation taken with a miniature camera, the processing of the resulting video image, and the machining of a ceramic block controlled by a computer. Besides the delicate tooth preparation powdering process (to block light reflections during optical impression), another shortcoming of the system is the difficulty to adequately position the camera over second molars and in patients with limited mouth opening. An additional criticism of this method is the simplified occlusal anatomy resulting from the cutting of very hard porcelain or glass ceramic. Nevertheless, CEREC is the only semi-direct technique that can be recommended to restore an endodontically treated tooth in the form of a porcelain overlay (complete occlusal coverage). In this case, total occlusal coverage (overlay) is recommended (see Section 6). The CELAY pantograph is based on the duplication of an intra-orally made resin inlay into a ceramic inlay. This procedure also requires good operatory access to complete the original inlay. As is the case with the CEREC, this system suffers from shade uniformity and simplistic anatomy; unless an additional porcelain firing is made.

Extraoral composite inlays/onlays. The interesting feature of this approach is to extemporaneously fabricate the inlay/onlay using a hard, fast-setting silicone model. Alginate for the impression and a combination of bite

Figure 5. Proximal ridges are intact on this molar, which represents the ideal indication for direct composite restoration (a). Cavity preparation after caries removal, beveling and bonding (b). Composite was stratified using the so-called "sandwich" technique, comprising a base of dentin-like shades (c-e) that are characterized with intense stains (f) and covered with more translucent masses (g-j). Each cusp and anatomical lobe can be cured separately, which allows the elaboration of an extremely sophisticated morphology and functional masticatory surface (k).

Figure 5a.

Figure 5b.

Figure 5c.

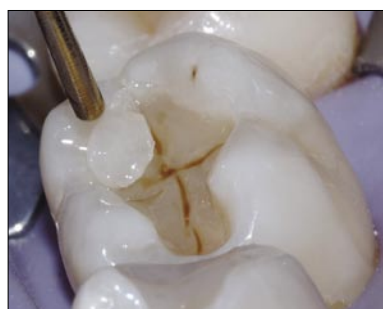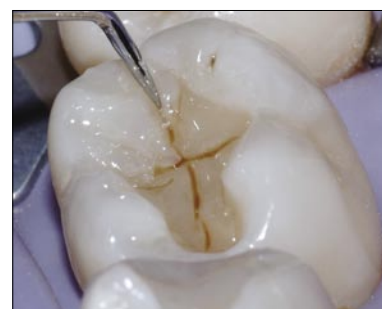Figure 5d.

Figure 5e.

Figure 5f.

Figure 5g.

Figure 5h.

Figure 5i.

Figure 5j.

Figure 5k.

Figure 6a.

Figure 6b.

Figure 6c.

Figure 6. Large MOD cavities on teeth Nos. 30 and 31 are ideal for extraoral inlays. Using an alginate impression (a) and fast-setting silicon materials (b, Blue Mousse and Mach 2, Parkell), individual working dies (c) were obtained in six minutes.

registration material (e.g. Blu-Mousse, Parkell, Farmingdale, N.Y., and flexible hard silicone (e.g. Mach 2, Parkell) for the working model can be used (**Figure 6**, from impression to finished dies in six minutes). Unlike the intraoral technique, small undercuts in the preparation are tolerated. The inlay can always be removed from the elastic model and be seated in-mouth after the corresponding intraoral adjustments have been made. The esthetic potential and anatomy of extraoral composites is greatly improved by the possibility of performing more sophisticated layering than can be accomplished intraorally. As in the case of intraoral inlays, post-polymerization treatment is also indicated (placing the restoration into an oven at 212 degrees for a few minutes). In addition to improving restoration adaptation and seal because the main polymerization shrinkage is achieved without stress on the adhesive interface, the initial goals of semi-direct techniques were also to facilitate clinical procedures and to improve occlusal anatomy, contact points and related function. Today, these objectives have globally been achieved at the expense of a longer treatment time and higher treatment fees. However, it offers the only reasonable alternative in cases that cannot be treated by direct restorations

or do not justify the use of indirect techniques. A 14-year follow-up view of an intraoral inlay is featured in **Figure 2d**.

Section 6. Clinical Considerations About Indirect Ceramics

The comparatively low elastic modulus of most composites can never fully compensate for the loss of strong proximal enamel ridges, especially in extremely large Class II restorations. In these situations, including those with cusp coverage, indirect ceramic inlays/onlays seem to be best alternative.[31,35,58,59] In the particular case of total occlusal coverage in vital teeth with a short clinical crown, ceramic indirect overlays are indicated.[34,35,58,59] Luting procedures of semi-direct and indirect bonded restorations follow the same specific steps described elsewhere including the immediate application of the dentin bonding agent (before impression taking) and use of a regular light-curing composite as the luting agent.[60,61] Dual-cure composite cements can be omitted in this approach because bonded porcelain restorations seem to offer sufficient translucency for effective light curing.[62] The rigorous application of this sequence is imperative to avoid postoperative sensitivity.

Tooth preparation. As is the case in direct restorations, outline preparation

form initially depends on the extent of the caries, demineralization of adjacent enamel, discoloration of enamel or dentin that might have a negative effect on esthetics and the geometry of the restoration to be replaced. For metallic restoration replacement, the general cavity design is already determined and the preparation has to be completed by the tapering of proximal margins after removal of any damaged tissues. Dentin undercuts resulting from existing cavity design or caries removal do not need to be eliminated as these concavities will be filled by the associated application of immediate dentin sealing and composite before making the impression (see next section). To allow for the use of solely light-cured composite luting agents, cavities deeper than 4 mm at the occlusal level and 6 mm at the proximal level will require the placement of a composite base. Deep subgingival proximal margins must be elevated with a direct composite provided that rubber dam and matrix placement (tight adaptation) is possible.[63] If successful isolation and adaptation of the composite cannot be achieved, surgical exposure of the margin will be required prior to restoration. For optimal finishing and adaptation, occlusal and proximal shoulder margins are recommended. Thin isolated remaining cusps (< 2 mm at the base or when
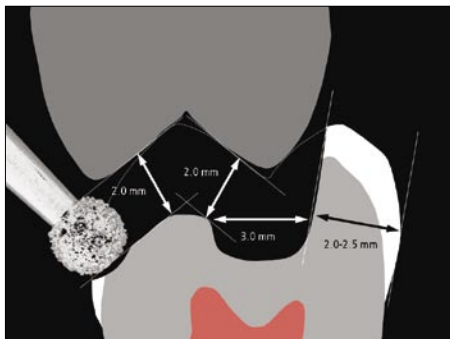
Figure 7. Recommendations for porcelain restoration dimensions. Note the "hollow chamfer" margin design that can be obtained with a round bur to ensure both an optimal marginal adaptation and a nice esthetic blending.

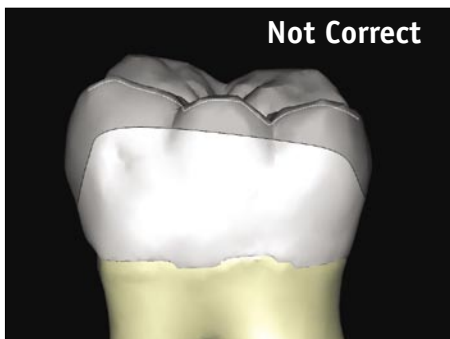**Figure 8.** KaVo Prep Ceram (Nos. 51 and 52) tapered tip with optimal "inlay box" shape.

Figure 9a.

Figure 9b.

Figure 9. In case of conservative (less esthetic) type of cuspal coverage, one must be careful to follow the tooth anatomy to allow sufficient clearance not only at the cusp tip (a), but also at the level of secondary grooves (b).
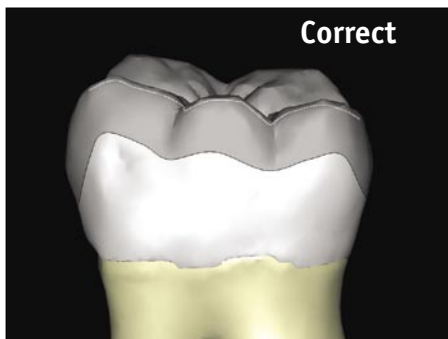
the occlusal margin is located at the cusp tip) should be covered to ensure a 2 mm overlap of restorative material. In this case, a hollow chamfer will assure both an optimal marginal adaptation and a nice esthetic blending (**Figure 7**). The proximal and occlusal extensions can be kept as minimal as possible and can be placed in contact areas. As for direct composites, proximal cavity margins can be shaped and finished efficiently without risking damage to the adjacent dentition through the use of specific oscillating diamond tips. Prep Ceram tips (Nos. 51 and 52, KaVo) are specially developed for adhesive inlays and onlays with optimum taper (**Figure 8**). Their use

is also recommended after immediate dentin sealing in order to clean enamel from excess adhesive resin.

In case of more conservative (less esthetic) type of cuspal coverage, one must be careful to follow the tooth anatomy to allow sufficient clearance not only at the cusp tip but also at the level of secondary grooves (**Figure 9**). Groove areas are always characterized by high stress concentrations and also need to be supported with material thickness.[35] A preliminary wax-up and corresponding silicone guides are recommended in difficult cases.

Immediate dentin sealing, base lining and dentin build up. With the

development of improved adhesives and immediate dentin sealing, the use and indications for base-liners have decreased.[61] This group of materials traditionally performs many different functions, including the "partial lining" as a biologic protection for deep preparation areas, the "total lining" for the dentin insulation against chemical or thermal injuries, and the dentin replacement as a "base" prior to further restoration procedures.[58] Today, the indication for placing a liner under an adhesive restoration is mainly for pulp protection in the form of a "partial lining" using $Ca(OH)_2$ cements.[64,65] Modern adhesives are capable replacing the "total lining" function of former varnishes and cements. Base materials are mainly indicated to reduce the volume of the inlay/onlay (e.g. excessive depth) and to create an adequate preparation geometry by providing an even cavity floor and filling up internal undercuts. For that purpose, different materials can be used. Historically, when fluoride release seemed beneficial because of high risk of restoration leakage, glass ionomers were considered.[66-68] Traditional zinc phosphate cement was also applied as a base material since its biocompatibility was demonstrated by long-term clinical use and histological study.[69] Today, internal undercuts should be filled with resin-based materials (resin-based glass ionomer or composites) to avoid destructive preparations. In severe carious lesions, the selective removal of decayed tissue may create undercuts, which are not compatible with the application of an indirect restoration. To preserve and reinforce remaining sound tooth structure, the internal tapered design should be maintained by the application of bases and/or liners (**Figure 10**).[59,61,70,71] Reducing the volume of the inlay/onlay will also facilitate the light curing of the luting agent. Use
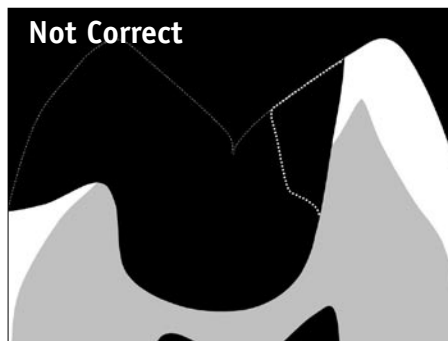
Figure 10a.

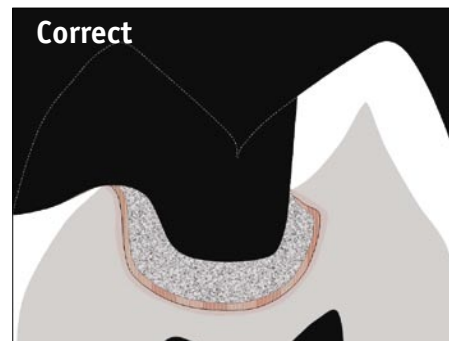**Not Correct**

Figure 10b.

Correct

Figure 10c.

Figure 10. Large restorations, especially those that are deep in a pulpal direction, require a base build-up in order to have porcelain depth not greater than 3.0-4.0 mm. With extreme undercut walls, due to caries or prior restoration (a), instead of removing more tooth structure to get a proper path of insertion for the restoration and weakening the walls (b), use composite to fill in the undercut walls in order to preserve tooth structure (c).

Figure 11. Total occlusal coverage (overlay) is recommended on an endodontically treated tooth. A 2 mm glass ionomer (GIC) base is recommended at the pulpal floor, as it will facilitate eventual re-entry for endodontic reasons. Composite is used in conjunction with immediate dentin sealing (IDS, red interface) to reduce the volume of the inlay/ onlay (e.g. excessive depth) and to create an adequate preparation geometry (by providing an even cavity floor and filling up internal undercuts).

of rubber dam is mandatory during base-lining and bonding procedures. It must be said that adequate isolation of the operating field by other means is not acceptable for posterior adhesive procedures.

Endodontically treated teeth. Endodontically treated teeth are more susceptible to fracture, not because of pulp removal per se, but due to the increased strain resulting from tooth substance loss.[72] For posterior teeth, total cuspal coverage with porcelain is

recommended as it will significantly stiffen the crown and increase cusp stabilization.[35,73] As described for vital teeth, a composite resin base is indicated (**Figure 11**) to reduce the volume of the inlay/onlay and to create an adequate preparation geometry (by providing an even cavity floor and filling up internal undercuts). An additional reason for using a composite resin base in conjunction to immediate dentin sealing is the improved marginal seal and stabilizing effect of the base, reducing the risk of cusp fracture during the time between cavity preparation and the insertion of adhesive inlays.[71]

Adhesion to the existing adhesive and composite base. Immediate dentin sealing and base lining serves to protect exposed dentin between preparation and delivery of the final ceramic restoration. This procedure not only enhances bonding and protection of the pulp but prevents tooth sensitivity during the provisional phase. It has been established that a filled adhesive like Optibond FL can be efficiently reactivated by roughening with a large grained diamond or by roughening with microsandblasting.[61,74,75] This limits the final bonding procedure to enamel conditioning and application of an adhesive resin. **CDA**

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