Esthetic Restorations for Posterior Teeth: Practical and Clinical Considerations

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The current abundance of posterior esthetic restorative materials and techniques may be confusing. This paper describes a simple and logical global concept that assists clinicians in choosing the appropriate therapeutic modality according to well-defined clinical criteria. Practical considerations about cavity preparation, base-lining, filling, luting, and finishing procedures are reviewed. (Int J Periodont Rest Dent 1996;16:105–119.)

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The ideal material for posterior esthetic restorations unfortunately does not yet exist. Many cases, however, can be treated successfully by selection of the appropriate therapeutic modality from the wide range of restorative products and procedures available. The related literature is abundant but may give the clinician information that is rather sketchy and therefore difficult to integrate. Consequently, there is a need for a treatment strategy and a classification of materials and techniques that can be logically applied in each clinical situation.[1] The following therapeutic strategy is based on an updated review of the properties of restorative materials.

Restorative materials

Adhesives

All modern esthetic restorative systems rely on adhesive procedures. Enamel adhesion through the acid-etch technique has been proven to be effective, whereas dentin adhesion remains perfectible. The latest formulations of dentin bonding agents (DBA) rely on the use of hydrophilic monomers, generally preceded by dentin etching.[2] The rationale behind these adhesives is to penetrate superficially the etched dentin or treated smear layer and underlaying dentin. The formation of a "hybrid layer" or "interdiffusion zone" made of intimately linked resin and dentinal tissues (mainly collagen fibers) provides a real improvement of the in vitro dentin bond strength compared to previous DBA formulations.[3] However, because of the lack of clinical performance reports, it cannot be ascertained that these new dentin adhesives justify the enlargement of the indications of bonded restorations to preparations extending below the cementoenamel junction.

Base liners

With the development of more effective adhesives, the use and indications of base liners have decreased. Currently, 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 (insulation against chemical or thermal injuries).[4,5] Modern adhesives seem to replace the "total lining" function of former varnishes and cements. Base materials are mainly indicated to reduce the volume of the filling material and to confer an adequate geometry on preparations for inlay/onlay techniques (by providing an even cavity floor and filling up internal undercuts). For that purpose, different materials can be used; however, none is really ideal. When fluoride release seems beneficial (suspicion of restoration leakage) glass-ionomer–based cements should be considered.[6-8]

Filling and luting materials

Both composite resins and ceramics may be used as filling materials. If composite resins are used, the light-cured fine hybrids or the monomodal brand (Z100, 3M) constitute the best choice.[1,9] Modern kits of "all-purpose composites" do provide a large range of opacities and shades (generally matching the Vita shade guide, Vita Zahnfabrik). This gamut of colors, mandatory for anterior fillings, may also improve the esthetic potential of posterior restorations.

The most critical aspect of current composite materials remains the unavoidable resin shrinkage. Compensation for resin-curing contraction was the key goal for developing innovative filling techniques and to promote luted restorations. In the case of ceramic inlays/onlays, whatever technique is chosen, the success of the restoration relies mainly on a strong bond to the tooth obtained by ceramic etching and silanization, as well as the use of a composite luting cement.[10-12] Composite resins also appear to be the only appropriate luting cement for composite restorations. Again, the dual-cure fine hybrid products are the best choice.

Esthetic restorative techniques

Esthetic restorative techniques for posterior teeth can be categorized into three groups[1,13]: *(1)* the direct techniques that consist only of intraoral procedures that require a single appointment; *(2)* the semidirect techniques that include intraoral as well as extraoral procedures to produce a luted chairside restoration; and *(3)* the indirect techniques that require several appointments and the collaboration of a dental laboratory.

The aim this article is to present a practical and clinical guideline for modern posterior esthetic restorations.

Cavity preparation strategy

For preparation of a tooth from the perspective of an adhesive restoration, the principle of maximum tissue preservation must be respected. For posterior teeth, this implies that certain structures such as proximal ridges, enamel bridges, and sound occlusal surfaces have to be preserved, even where the enamel is not fully supported by dentin. For adhesive direct fillings, the conventional geometry of Black cavities is not optimal. Lutz et al[14] described the "adhesive preparation" consisting of conservative round or ovoid proximal box-and-occlusal extensions, including beveling of enamel margins.

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 ("beveled conventional preparation"). Luted restorations (semidirect and indirect) require tapered cavities with butt margins. Internal undercuts are preferably filled with a base material to avoid destructive preparations. Here also, rounded internal and external lines are preferred.[15] Such a design improves mechanical stress distribution and makes possible the fabrication of accurate fired ceramic inlays/onlays.

For computer aided design–computer aided manufacturing (CAD-CAM) restorations (eg, Cerec and Cerec II, Siemens),[16] preparation design depends on the milling system characteristics. The cavities must have a simple geometry, which may lead at times to the useless loss of sound tissue. Butt preparations roughly imply parallel sectioning of enamel rods.[17] It is known that acid etching in such conditions will not provide an optimal adhesion.[18] In that respect, the hollow chamfer preparation should improve adhesion to enamel and esthetic transition between restoration and tooth.

Restorative techniques

Even if a skillful operator can manage every clinical case with a single restorative technique, it will probably not serve the patient optimally. For instance, ceramic indirect techniques should not be applied for small Class I and II restorations, and direct composites should not be used for full-arch rehabilitations. In the first case, the patient would be charged for an oversophisticated treatment. In the other, the financial benefits would be largely counteracted by problematic occlusion management and marginal adaptation.

A rational clinical approach is therefore indicated. An overview of the appropriate choice of materials and techniques according to each clinical situation is presented in Fig 1 in the form of a diagrammatic and clinical guideline. The key to this guideline is the ability to superimpose each case on one of the eight lateral segment types, according to the number, size, and design of the cavities. The proposed treatment options take into consideration not only practical and clinical criteria, but also the respective biologic and physicochemical properties of restorative materials.

Since adhesive procedures are usually complex and tricky, a few basic requirements for successful bonding should be pointed out. First of all, the margins should be placed supragingivally or juxtagingivally. Whatever technique is chosen, the use of rubber-dam is also mandatory, as adequate insulation of the operating field by other means is not conceivable for posterior adhesive procedures.

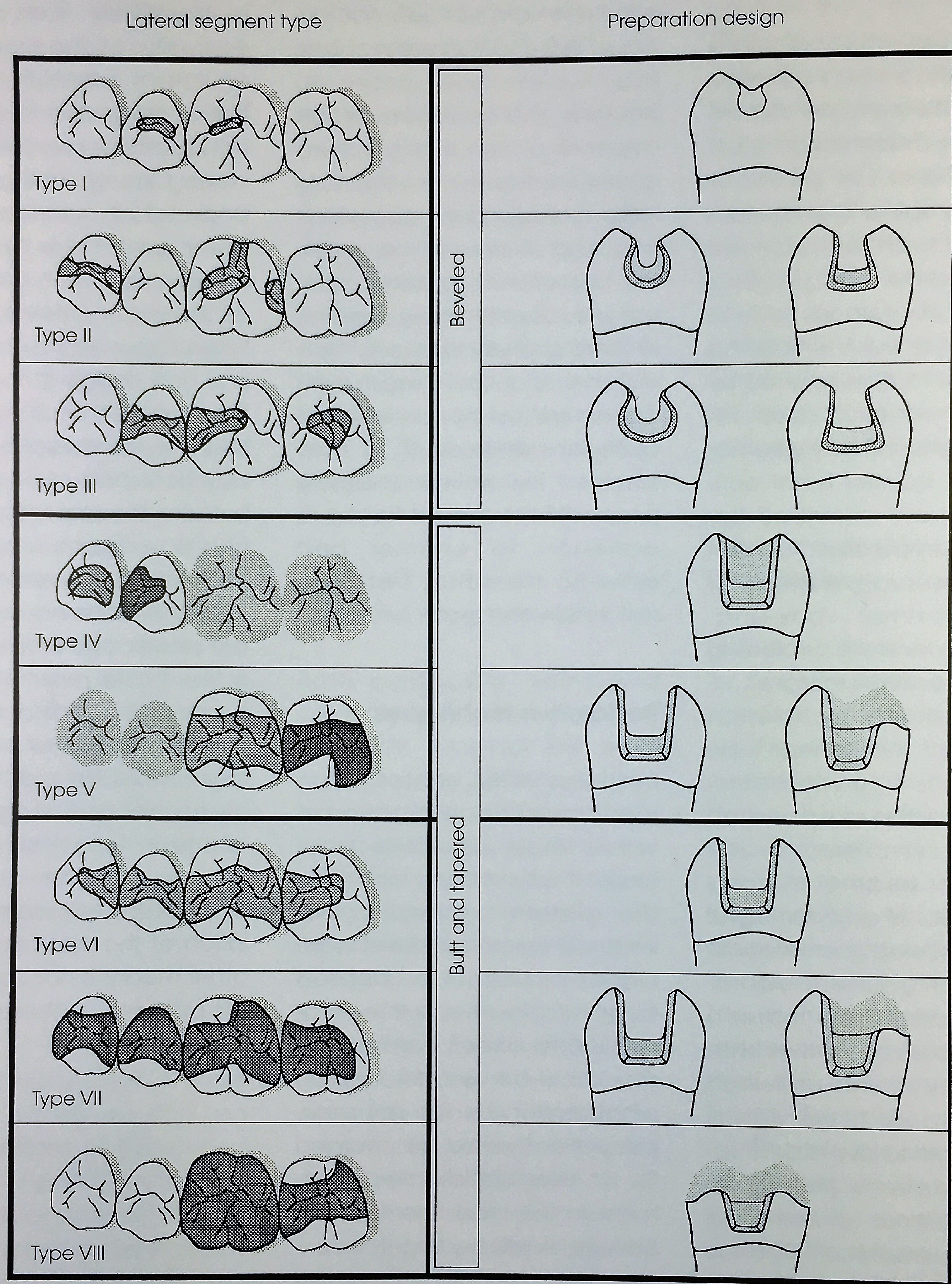
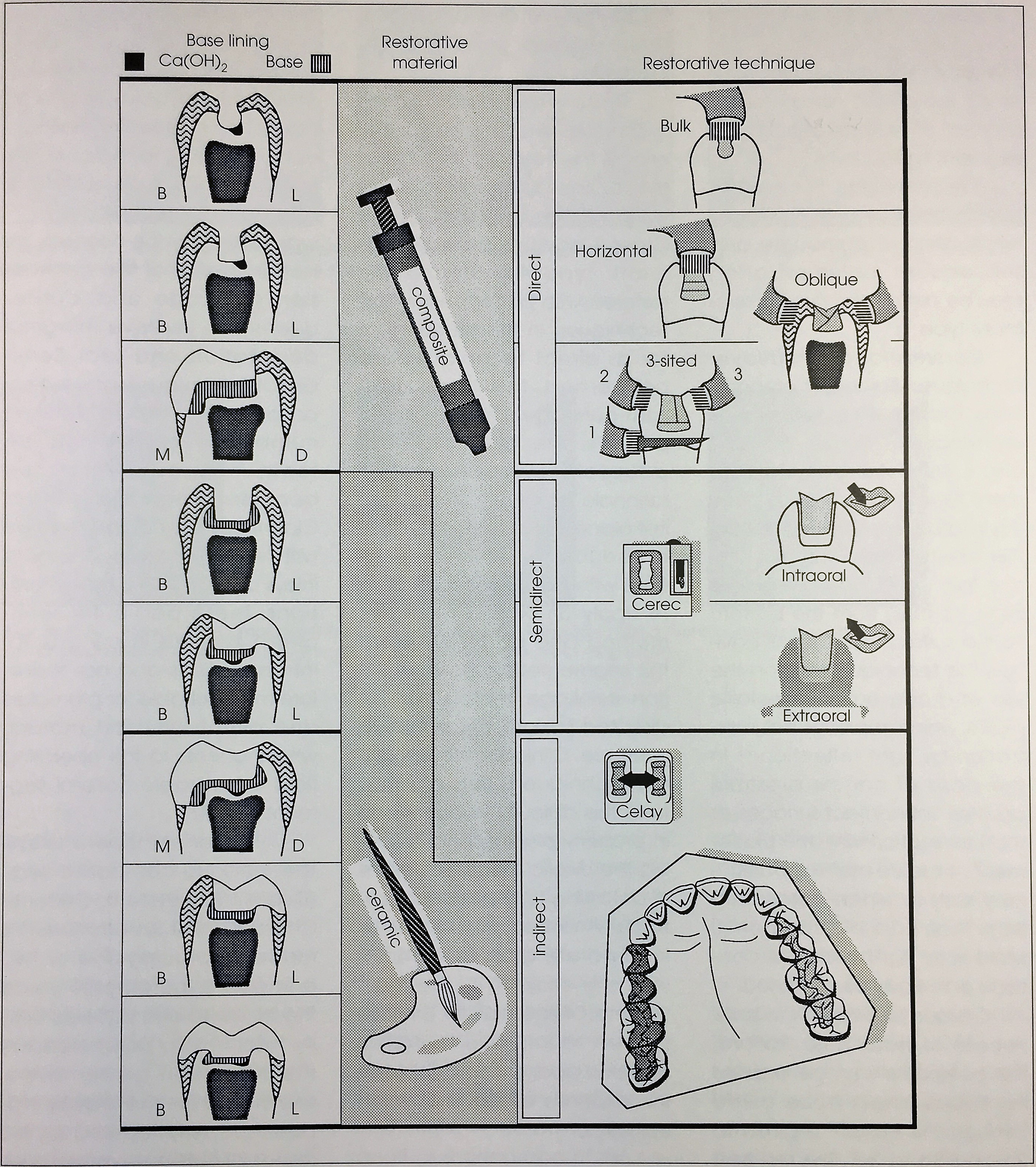


Fig 1 *Diagrammatic and clinical guideline for posterior esthetic restorations.*


Base lining
Ca(OH)2
Base
Restorative material
Restorative technique
B
L
M
D
composite
ceramic
Direct
Bulk
Horizontal
Oblique
3-sited
1
2
3
Semidirect
Cerec
Intraoral
Extraoral
indirect
Celay

Direct techniques

The direct techniques are generally indicated for a limited number of restorations (lateral segment types I to III).

Bulk technique. For preventive restorations only,[19] a single application of composite and subsequent polymerization may be performed (lateral segment type 1).

Conventional multilayer techniques. For larger preparations, multilayering techniques are required.[20] For small Class I and II restorations (lateral segment type II), a horizontal layering is to be applied. In practice, the cavity is filled with successive thin composite layers (less than 1.5 mm) from the bottom to the surface. For Class II cavities, this technique rests on the use of a conventional metallic matrix which improves polymerization by light reflection.[21] In the case of narrow proximal cavities, flat contact surfaces, or short clinical crowns, the placement of such a matrix is particularly simple when compared with that of a plastic matrix. Moreover, tight proximal contacts can easily be obtained.

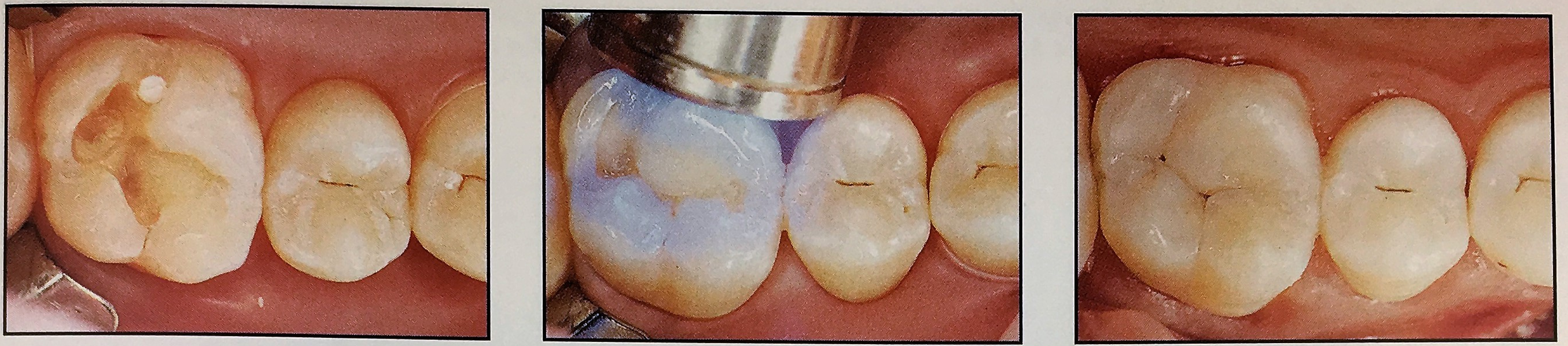
Oblique layering. Occlusally, in case of wider preparations, the composite may be applied in oblique layers to be cured through the cusps[22] (Figs 2a to 2c and 3a to 3c). This will limit the development of contraction forces between opposing walls, which could be detrimental to the restoration quality (stress build-up, gap formation, cuspal fissures).

Three-sited light-curing technique. Since horizontal layering is theoretically not able to fully compensate for polymerization shrinkage, medium-size Class II cavities (lateral segment type III) should be restored with better performing techniques. In this situation, as far as direct techniques are concerned, the three-sited light-curing technique should provide the best proximal adaptation and seal.[23] The rationale for this technique is to first place a glass-ionomer base to reduce the volume to be filled with composite, and then to apply an original multilayer method (see Fig 1). By use of this segmentation, polymerization shrinkage vectors can be directed toward the adhesive interface. Clinically this engaging technique suffers at times from the difficulty encountered in properly placing and adjusting the plastic matrix, as well as in obtaining tight proximal contacts. Another modality is to incorporate glass or ceramic inserts or inlays to fill the main volume of the cavity. This has proven to improve marginal seal and adaptation,[24,25] but at the expense of the restoration esthetics.

Semidirect techniques

Large Class I and II cavities (lateral segment types IV and V) cannot be adequately restored using a direct technique. The relatively recent development of semidirect techniques[16,26,27] was justified by the necessity for better control of the contraction shrinkage and, consequently, to improve marginal adaptation and seal. Semidirect 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 CAD-CAM restorations. These particular semidirect systems imply crucial intraoral steps and are therefore more suitable for premolars and eventually first molars, where access to the operating field is favorable (lateral segment type IV).

Intraoral composite inlays. The intraoral composite inlay (Direct Inlay System, Coltene; Chairside Inlay System, Kulzer) is made by placing one or two composite increments inside the insulated and coffered cavity. After in vivo polymerization, the inlay can be removed, showing that the cavity has been properly tapered (in this respect, MOD or complex cavities may be problematic because of the mesiodistal shrinkage component, which



Figs 2a to 2c Class I restoration preparation with palatinal extension (left). Oblique layering is applied to reduce polymerization stresses between opposite walls (center). Postoperative view (right).

Figs 3a to 3c Failed Class I amalgam filling to be replaced (left). A special layering technique together with the use of brown resin stain (center) give a natural appearance to this direct filling (right).

tends to lock the inlay into the prepared tooth). At this time, any desired correction may be performed (eg, proximal contact adjustment). The inlay can be additionally subjected to a photothermic treatment (postpolymerization process) in a special oven (DI 500, Coltene). This advisable procedure allows the optimal resin conversion rate to be reached in a few minutes, ensuring dimensional stability and maximal hardness of the composite material.[28]

CAD-CAM inlays. The only widespread CAD-CAM systems are Cerec and Cerec II, in which an optical impression of the preparation is taken with a miniature camera, and the processing of the resulting video image and the machining of a ceramic block are controlled by a computer. In addition to restrictions of the cavity design, another shortcoming of the system is the difficulty of adequately positioning the camera over last molars or in patients with limited ability to open their mouth. Finally, the simplified occlusal anatomy resulting from the machining and in vivo adjustment of very hard porcelain or glass-ceramic has been criticized. To overcome the high cost of CAD-CAM systems, copying machines such as Celay (Mikrona), and more recently Ceramatic MkII (Instrument AB), have been marketed for the production of chairside ceramic inlays and onlays. However, the Celay is now essentially used to produce restorations in the laboratory. Large Class I and II restorations for the most posterior teeth (lateral segment type V) may also be produced with CAD-CAM systems, even though the extraoral composite inlay is a more convenient technique.

Extraoral composite inlays/onlays. The interesting feature of the extraoral composite inlays/onlays (previously marketed as EOS, Vivadent; Inlay System, De Trey-Dentsply) is the extemporaneous fabrication of the inlay/onlay over a hard fast-setting silicon model (Figs 4a to 4e) obtained from either a simple alginate or condensation silicon impression material. As both original products were taken off the market, substitution materials must be used for fabrication of the model (ie, Blue Mousse, Parkell). Unlike the intraoral technique, small undercuts in the preparation are tolerated. The inlay can always be removed from the elastic model and be perfectly seated in vivo after the corresponding intrados adjustments have been made. The esthetic potential and anatomy of extraoral composites is greatly improved by the possibility of more sophisticated layering than an intraoral composite. As in the case of intraoral inlays, postpolymerization treatment is indicated. In addition to improvement in restoration adaptation and seal, the initial goals of semidirect techniques were to facilitate clinical procedures and to improve occlusal anatomy and related function. Today, these objectives have been achieved globally at the expense of a longer realization time and higher treatment fees. However, semidirect techniques offer the only reasonable alternative in cases that cannot be treated by direct fillings or do not justify the use of indirect techniques.

Indirect techniques

Serial cavities (lateral segment types VI and VII) cannot be properly restored with the techniques already described. The challenge of serial restorations is to master not only esthetics, adaptation, and seal, but also to satisfy all aspects of static and dynamic occlusion. An attempt to reach these objectives through the direct or semidirect techniques would require a segmented fulfillment, resulting in extended chairside time and senseless clinical efforts. Preparation characteristics and base lining indications for indirect techniques are the same as for semidirect techniques. Temporary restorations made of self-curing resin should maintain the protection of the prepared tooth and a minimal function. Specific materials such as Fermit (Vivadent) may also be used for intracoronal provisionalization. For serial restorations without cusp coverage (lateral segment type VI), indirect composite inlays seem preferable. The use of ceramic may also be advised, but it is uncertain whether the complex technical procedures involved and their related costs offer a better prognosis. Moreover, the manipulation of composite inlays is less sensitive than that of ceramic ones, in particular during try-in and cementation.

Indirect composite inlays. Current modern composite lab kits (eg, Herculite XRVlab, Kerr; Brilliant Indirect Esthetic System, Coltene; Tetric Lab Inlay, Vivadent) include the same materials as those designed for chairside use, mainly light-cured small particle hybrids. The available range of shades and opacities, as well as intensive colorings, make possible the realization of very natural restorations (Figs 5a to 5c). Postpolymerization should be systematically applied. For large serial restorations including cusp coverage (lateral segment type VII), indirect ceramic inlays/onlays are best indicated. Despite the lack of any clinical or scientific evidence, the use of current composites for large occlusal and stress-bearing rehabilitations seems questionable. In the particular case of total occlusal

Figs 4a to 4e *Semidirect extraoral composite inlays. Preoperative view of large Class II fillings to be replaced (a). A hard fast-setting silicone model of the prepared teeth, which could easily be separated, is made (b). Inlay fabrication using different composite colors and opacities (c). Completed inlays on their silicon dies (d) and final clinical view (e).*

Fig 4a

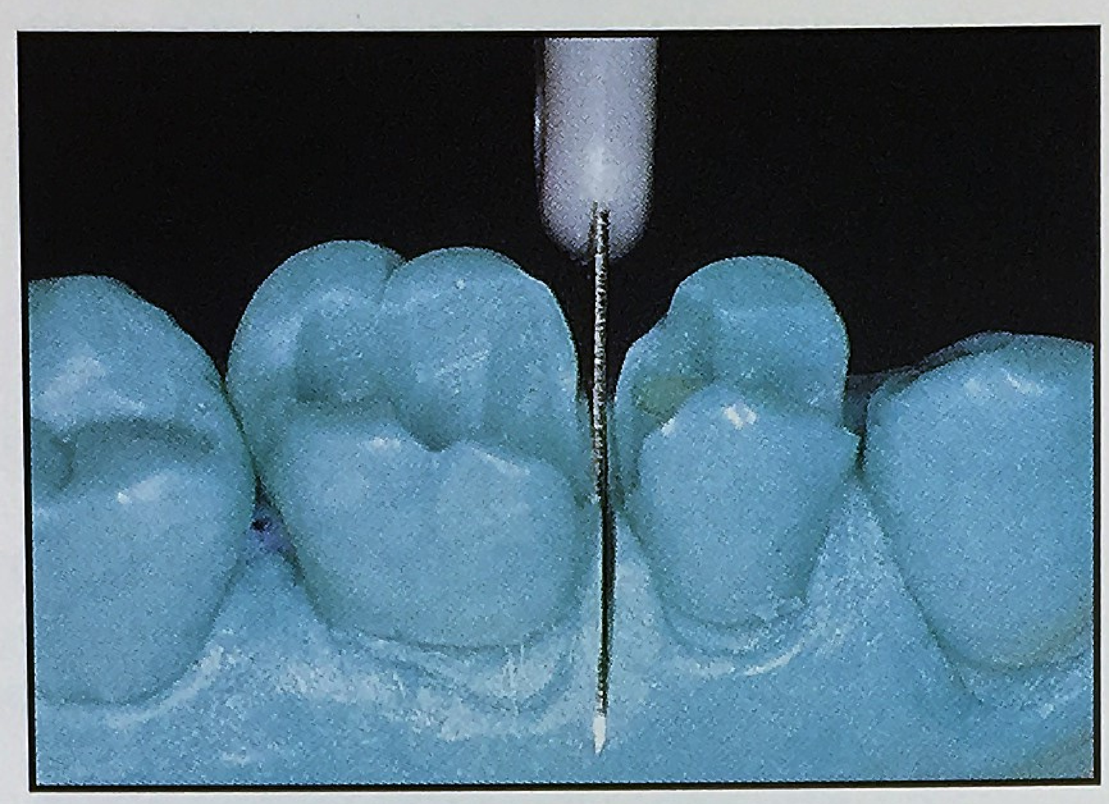


Fig 4b

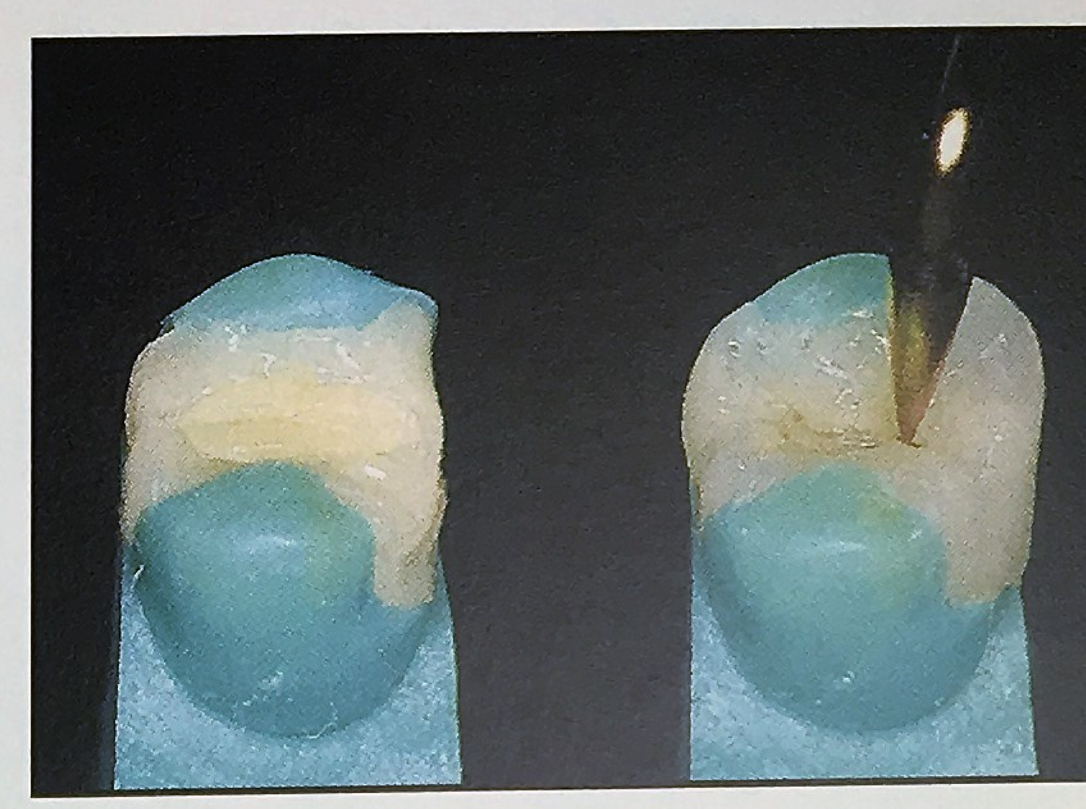


Fig 4c

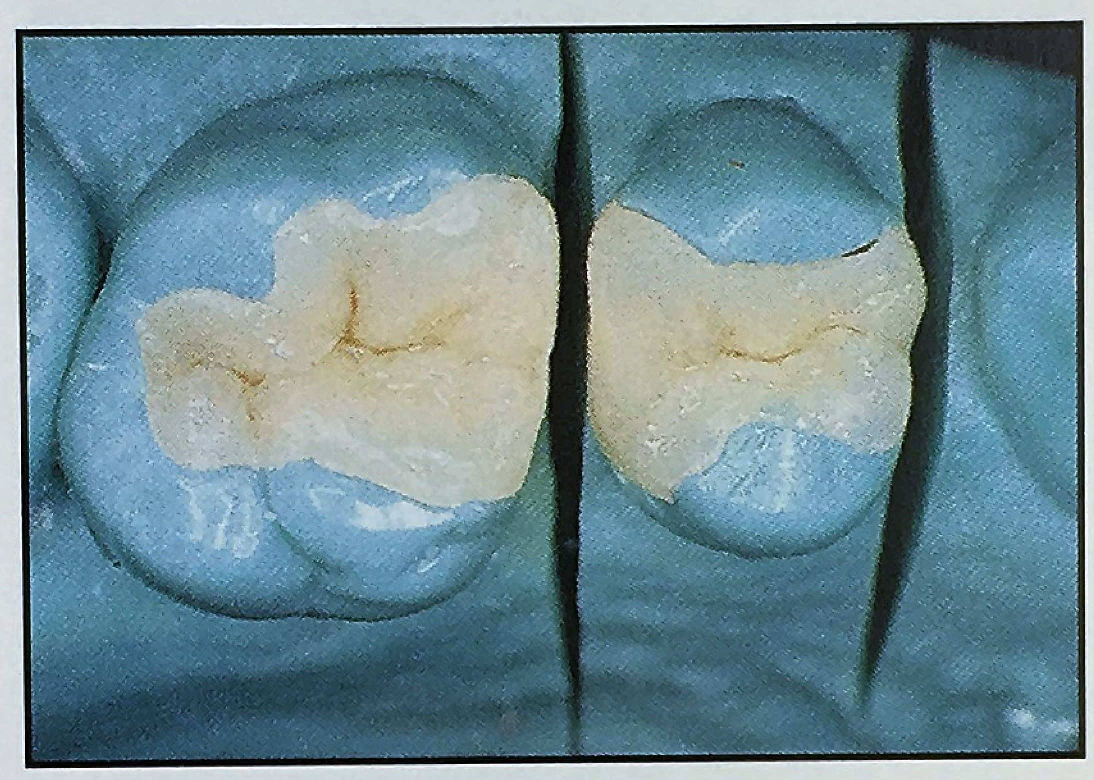


Fig 4d

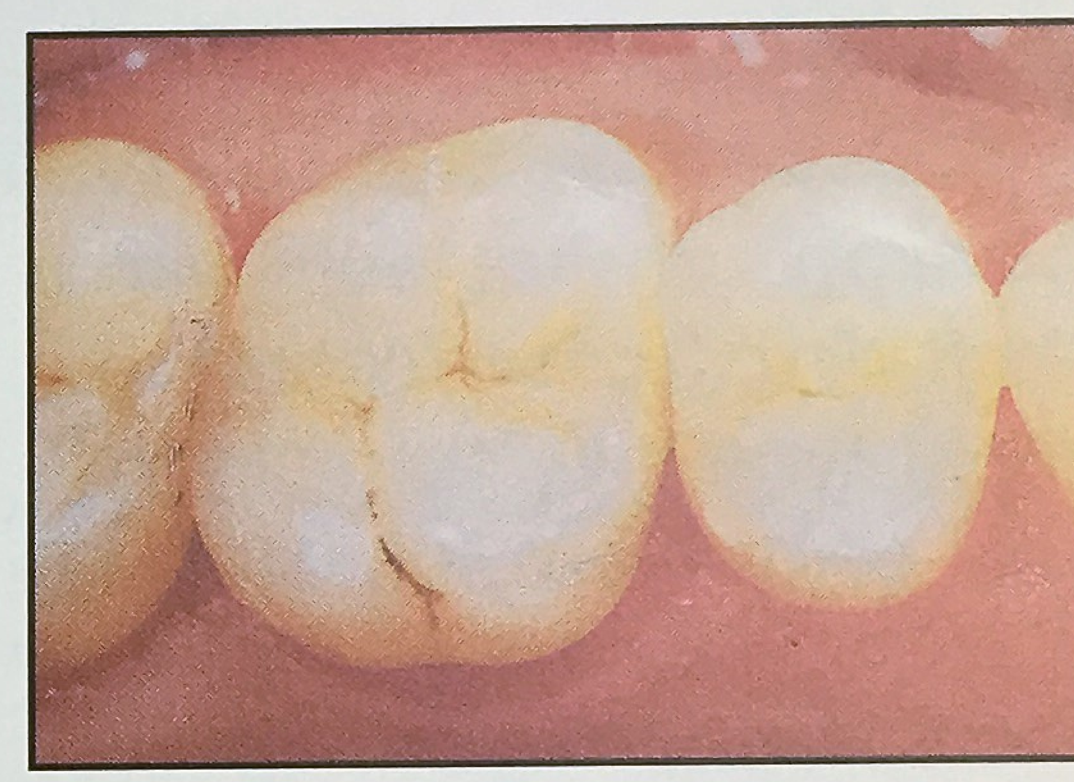
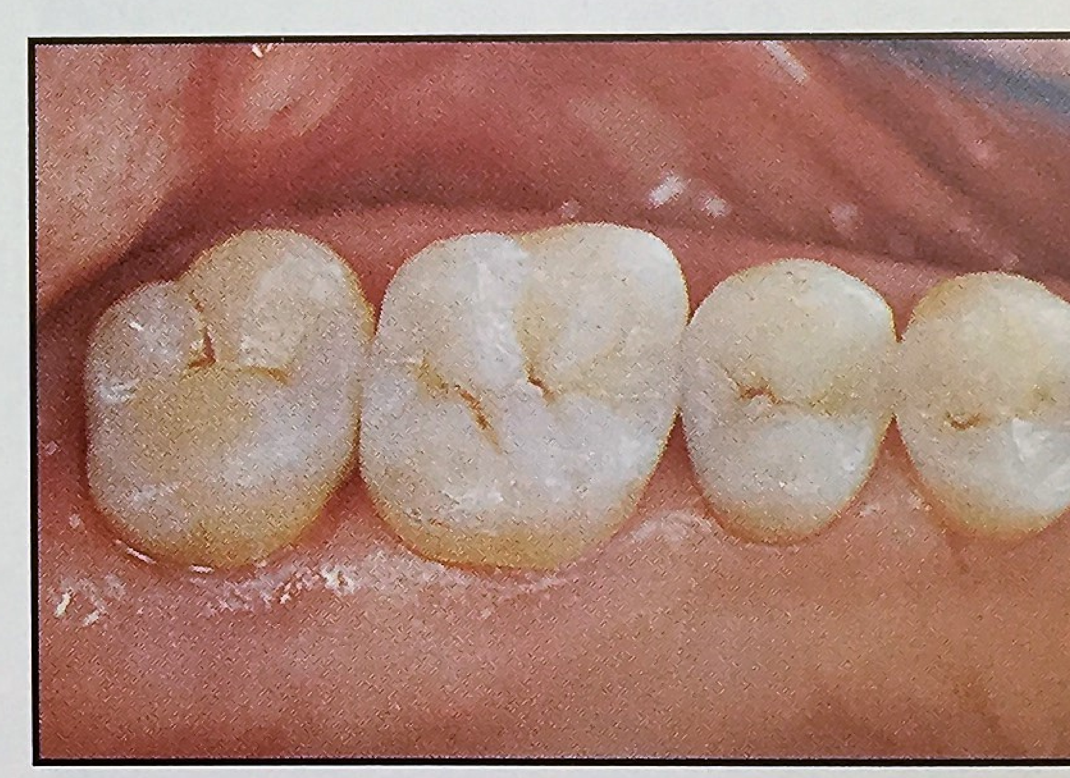
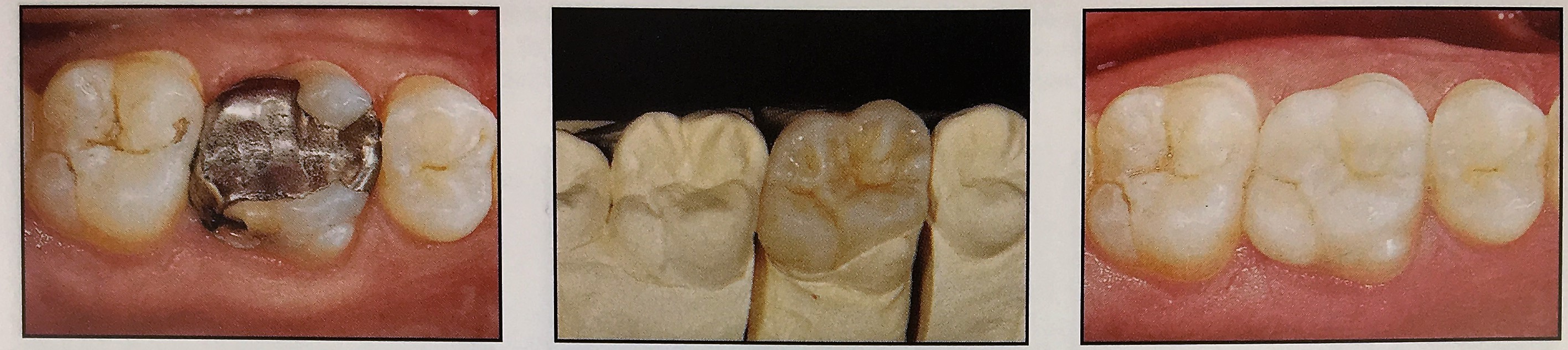


Fig 4e



Figs 5a to 5c *Serial intracoronal restorations. During the first clinical session, defective Class II amalgam fillings (left) were removed and temporaries fabricated (center). To achieve proper functional and esthetic rehabilitation, indirect composite inlays were laboratory-made (Dental technician, D. Vinci, University of Geneva, Geneva, Switzerland). Postoperative view (right).*



Figs 6a to 6c Full occlusal coverage of a single tooth. Preoperative view (left). Insufficient remaining thickness of cusps justified coverage of the complete tooth, but the latter was kept vital. Final view of the ceramic overlay on its single dye (Dental technician, M. Magne, Oral Design Center, Montreux) (center) and after cementation (right).

coverage of vital teeth with a short clinical crown (lateral segment type VIII), ceramic indirect restorations are also indicated (Figs 6a to 6c). The realization of a ceramic overlay is indeed a judicious way to delay more invasive procedures of placing a crown, including root canal therapy and surgical crown lengthening (Fig 7).

Indirect ceramic inlays/onlays/overlays. Following are the various techniques currently in use:

1. Fired ceramic over refractory die is the oldest[29] and the most widespread method (eg, Vitadur, Vita Zahnfabrik; Optec, Jeneric/Pentron) for which reinforced porcelains are used. The main advantage of this technique is that no special equipment is required; however, the method is tricky and time-consuming. A recently developed and interesting approach has been to combine a very low-fusing ceramic fired over a conventional ceramic core (LFC, Ducera).[30] This method allows not only the simplification of lab procedures, but also produces excellent surface characteristics of the ceramic. The homogeneous glassy structure without crystalline phase provides perfect in vivo polishability, and is more friendly to opposing teeth than conventional composite ceramics.
2. Cast glass-ceramic restorations (Dicor, Caulk/Dentsply), similar to cast gold restorations, require special and expensive equipments. The material exhibits interesting physical and chemical properties,[31,32] but the high investment cost for the lab and the restricted esthetics have limited the development of this system.
3. The heat-pressed ceramic technique (Empress, Ivoclar), also based on the lost wax technique,[33] offers two elaboration modalities; the leucite-reinforced pressed porcelain is used to fabricate either the entire restoration or only a core. The second option allows esthetic improvements and characterization by additional ceramic firing.
4. Slip casting (In-Ceram Spinell, Vita Zahnfabrik), originally marketed for all-ceramic crowns, is based on the fabrication of a highly resistant aluminous core made of sintered alumina infiltrated with glass.[34] Its adaptation to intracoronal restorations,

Fig 7 *Comparative view of a porcelain fused-to-metal crown and ceramic overlay. The advantage of the overlay (adhesively luted) for vital teeth with a short clinical crown is obvious.*

based on the use of spinel ($MgAl_2O_4$) instead of alumina (Al_2O_3), is now available and presents the best mechanical properties among all systems previously described.

5. Machined ceramic (Celay) is now more popular for lab use than for chairside use. The original resin inlays are made on the master model, duplicated in ceramic, and may be completed by an additional porcelain firing.

Mixed indications

Some cases may result from a combination of the described lateral segment types. It is common to find different degrees of decay in the same arch. It is therefore logical to associate various restorative techniques or materials (Figs 8a to 8d).

Figs 8a to 8d *Mixed indication. The same quadrant presents different degrees of decay* (a). *The composite appeared to be the material of choice for intracoronal restorations, whereas ceramic was more appropriate for the coverage* (b, c). *Completed restorations in vivo* (d).

Fig 8a

Fig 8b

Fig 8c

Fig 8d

Luting procedures

The luting of semidirect or indirect restorations implies a critical *double bonding*. This turns the luting into a very sensitive step of the restoration as a whole. *Tooth–composite bonding* should be considered in relation to the nature and configuration of the substrate (enamel, dentin, enamel-dentin ratio, and presence of a base lining or varnish). A successful marginal adaptation and seal may be achieved when enamel completely surrounds the preparation limits.[35] Where free marginal or internal dentin surfaces exist, the application of a modern dentin bonding agent is advisable to improve the restoration seal[35] and prevent postoperative sensitivity.[36] For surfaces covered by a base-lining cement or varnish, no special procedure is required. The bonding to these materials does not appear advisable, considering that their weak dentin adhesion would probably fail when submitted to luting composite shrinkage and further function stresses.[37] *Composite–ceramic bonding* generally relies on the standard procedures of ceramic etching and silanization.[10] This combination of micromechanical anchorage and chemical coupling proved to be more efficient than each single procedure.[38,39] The heat-curing of the silane can improve the composite-to-ceramic bond.[40] Preactivated silanes probably do not perform as well as chairside-activated products.[41] A layer of adhesive must still be applied to the pretreated ceramic without curing. *Composite–composite bonding* is usually achieved by roughening and application of a thin adhesive resin layer on the inlay intrados.[42] Some clinical and in vitro data question the efficiency of this procedure.[43,44] Sand-blasting and silanization of the composite have been proposed to tentatively improve this bond. The complete polymerization of light-activated luting composites can be obtained only under a thin layer (less than 1.5 mm) of translucent and clear restorative material.[45] As these conditions are rarely encountered in clinical reality, the use of dual-cure adhesive and luting materials is strongly recommended. However, proper light activation remains essential to ensure an optimal conversion rate of the material.[46] From a practical viewpoint, the low viscosity of most dual cements makes their clinical use tricky. New formulations of highly filled luting composites developed for ultrasonic-assisted insertion perform better in this regard.

Finishing procedures

The restoration surface and margin quality depend on the nature of the material,[47,48] the restorative technique,[49] and the finishing methods and instruments.[50,51] For composites, the fine finishing is preferably performed using flexible discs for flat surfaces and fine diamond burs for irregular ones. Gingival margins are finished with aluminous or glass–metal strips. A final polishing with pastes may improve surface smoothness[48]; however, clinical experience showed that such improved gloss will not survive more than a few days in vivo. Pore-free ceramics, such as low-fusing ceramics (LFC, Ducera) or machinable ceramics (Dicor MGC, Dentsply), can be polished to a clinically satisfactory gloss with flexible discs, silicone points, and special diamond polishing pastes.[49,51] For other kinds of ceramics, finishing procedures should be reduced to occlusal adjustments, as these materials are extremely difficult to repolish in vivo. Polymerization shrinkage of composites used as direct filling material or luting cement, together with finishing procedures, may lead to the development of marginal defects. These defects can tentatively be sealed with a low viscosity resin.[52,53] It seems preferable to perform this "rebonding" before the polishing procedures, as the produced "smear" could probably fill these gaps. It is also warrantable to polymerize the rebonding resin under the protection of a glycerin jelly (eg, Air-Block, De Trey-Dentsply). This will provide complete polymerization of the resin surface (suppression of the "inhibition layer" resulting from resin polymerization inhibition by oxygen)[54,55] and prevent an accelarated wear of this incompletely cured layer.

Conclusions

Because of the considerable development of restorative materials and techniques, the clinician is currently faced with numerous esthetic treatment modalities. Consequently, the appropriate choice for a given clinical situation has become increasingly complicated considering the specificity of current bonded restorations. The concept proposed for dealing with this matter rests on distinguishing between different "lateral segment types" and their correlated treatment options. Eight possible lateral segment types can be defined according to the extent of decay. Small Class I to medium-size Class II cavities are restored with direct techniques ranging from bulk filling to more sophisticated multilayering methods. Larger cavities, when in a limited number, are suitable indications for semidirect techniques; a wide choice of chairside ceramic or composite inlay techniques may be applied. When dealing with serial restorations to full-arch rehabilitations, indirect techniques using composites or ceramics are best indicated.

References

1. Dietschi D, Magne P, Holz J. Recent trends in esthetic restorations for posterior teeth. Quintessence Int 1994;25:659–677.
2. Van Meerbeek B, Vanherle G, Lambrechts P, Braem M. Dentin and enamel bonding agents. Curr Opin Dent 1992;2:117–127.
3. Barkmeier WW, Cooley RL. Laboratory evaluation of adhesive systems. Oper Dent 1992;(suppl) 5:50–61.
4. Virgillito A, Holz J. Produits adhesifs dentinaires et de scellement soumis au contrôle biologique in vivo. J Biol Buccale 1989;17:209–224.
5. Elbaum R, Remusat M, Brouillet JL. Biocompatibility of an enamel-dentin adhesive. Quintessence Int 1992;23:773–782.
6. Schwarz ML, Philips RW. Long-term F release from glass-ionomer cement. J Dent Res 1984;63:158–160.
7. Hattab FN, El-Mowafy OM, Salem NS, El-Bradawy WAG. An in vivo study on the release of fluoride from glass-ionomer cement. Quintessence Int 1991;22:221–224.
8. Tam LE, McComb D, Pulver F. Physical properties of proprietary light-cured lining materials. Oper Dent 1991;16: 210–217.
9. Ferracane JL. Using posterior composites appropriately. J Am Dent Assoc 1992;123:53–58.
10. Simonsen RJ, Calamia JR. Tensile bond strength of etched porcelain (abstract 1154). J Dent Res 1983;62: 297.
11. Calamia JR, Simonsen RJ. Effect of coupling agents on bond strength of etched porcelain (abstract 79). J Dent Res 1984;63:179.
12. Dietschi D, Maeder M, Meyer JM, Holz J. In vitro resistance to fracture of porcelain inlays bonded to tooth. Quintessence Int 1990;21: 823–831.
13. Dietschi D, Holz J. Restaurations des dents postérieures. Rev Mens Suisse Odontostomatol 1990;100:1325–1332.
14. Lutz F, Lüscher B, Ochsenbein H, Mühlemann HR. Die Entwicklung der perfekt adaptieren, randspalffreien MOD-Kompositfüllung, In-vitro-Befunde. Schweiz Mschr Zahnheilk, 1976;86:1025–1041.
15. Fisher DW, Caputo AA, Shillingburg HT, Duncanson MG. Photoelastic analysis of inlay and onlay preparations. J Prosthet Dent 1975;33:47–54.
16. Mormann WH, Brandestini M, Lutz F, Barbakow F. Chairside computer-aided direct ceramic inlays. Quintessence Int 1989;20:329–339.
17. Boyde A. Anatomical considerations related to tooth preparation. In: Vanherle G, Smith DC (eds). Posterior Composite Resin Dental Restorative Materials. St Paul, MN: Peter Szulc, 1985:377–403.
18. Munechika T, Suzuki K, Nishiyama M, Ohashi M, Horie K. A comparison of the tensile bond strengths of composite resins to longitudinal and transverse sections of enamel prisms in human teeth. J Dent Res 1984;63:1079–1082.
19. Simonsen RJ. Conservation of tooth structure in restorative dentistry. Quintessence Int 1985;16:15–24.
20. Lutz F, Kull M. The development of a posterior tooth composite system, in vitro investigation. Schweiz Mschr Zahnheilk 1980;90:455–483.
21. Kays BT, Sneed WD, Nuckles DB. Microhardness of Class II composite resin restorations with different matrices and light positions. J Prosthet Dent 1991;65:487–490.
22. Weaver WS, Blank LW, Pelleu GB. A visible-light-activated resin cured through tooth structure. Gen Dent 1988;36:236–237.
23. Lutz F, Krejci I, Oldenburg TR. Elimination of polymerization stresses at the margin of posterior composite resin restorations: A new restorative technique. Quintessence Int 1986;17:777–784.
24. Donly KJ, Wild TW, Bowen RL, Jensen ME. An in vitro investigation of the effects of glass inserts on the effective composite resin polymerization shrinkage. J Dent Res 1989;68: 1234–1237.
25. Bott B, Hannig M. Optimierung plastischer Komposiffüllungen durch Keramikinserts. Deutsch Zahnärztl Z 1994;49:917–920.
26. Blankenau RJ, Kelsey WP, Cavel WT. A direct posterior restorative resin inlay technique. Quintessence Int 1984;515–516.
27. Eidenbenz S. Kopierschleifen keramischer Formkörper (Zahnmedizin Dissertation). Zürich: Univ of Zurich, 1992.
28. Bausch JR, de Lange C, Davidson CL. The influence of temperature on some physical properties of dental composites. J Oral Rehabil 1981;8: 309–317.
29. Bruce GA. The Herbst method of filling with glass. Dent Rec 1891;11: 47–48.
30. Komma O. Hydrothermal Dental Ceramics Systems. A New Category of Dental Material: Composition, Structure, and Characteristics. Rosbach, Germany: Documentation of Ducera Dental GMBH, 1993:2–7,25.

31. Pameijer CH, Grossman DG, Adair PG. Physical properties of a castable ceramic dental restorative material (abstract 827). J Dent Res 1980;52:474.
32. Adair PG, Grossman DG. The castable ceramic crown. Int J Periodont Rest Dent 1984;4:32–45.
33. Beham G. IPS-Empress: eine neue Keramik-Technologie. Ivoclar-Vivadent Report 1990;6:3–14.
34. Sadoun M, Degrange M, Heim N. Les céramiques dentaires. 2ème partie: les nouvelles céramiques. Journal de Biomatériaux Dentaires 1987;3:61–69.
35. Dietschi D, Magne P, Holz J. An in vitro study of parameters related to marginal and internal seal of bonded restorations. Quintessence Int 1993;24:281–291.
36. Haller B, Hofman N. Postoperative sensitivity: Mechanisms and prevention. In: Mormann WH (ed). International Symposium on Computer Restorations. Proceedings. Berlin: Quintessence, 1991:127–139.
37. Wieczkowski G, Joynt RB, Davis EL, Yu XY, Cleary K. Leakage patterns associated with glass-ionomer-based resin restorations. Oper Dent 1992;17:21–25.
38. Lacy AM, Laluz LJ, Watanabe LG, Delinges M. Effect of porcelain surface treatment on the bond to composite. J Prosthet Dent 1988;60:288–291.
39. Stangel I, Nathanson D, Hsu CS. Shear strength of the composite bond to etched porcelain. J Dent Res 1987;66:1460–1465.
40. Bailey LF, Bennet RJ. Dicor surface treatments for enhanced bonding. J Dent Res 1988;67:925–931.
41. Brönnimann R, Fritzsche T, Schärer P. Porzellan-Reparaturen. Schweiz Montsschr Zahnmed 1991;101:763–769.
42. Boyer DB, Chan KC, Reinhardt JW. Build-up and repair of light-cured composites: Bond strength. J Dent Res 1984;63:1241–1244.
43. Füllemann J, Kreji I, Lutz F. Kompositinlays: klinische und rasterelektronenmikroskopische Untersuchung nach einjähriger Funkctionszeit. Schweiz Monatsschr Zahnmed 1992;102:292–298.
44. Tam LE, McComb D. Shear bond strength of resin luting cements to laboratory-made composite resin veneers. J Prosthet Dent 1991;66:314–321.
45. Blackman R, Barghi N, Duke E. Influence of ceramic thickness on the polymerization of light-cured resin cement. J Prosthet Dent 1990;63:295–300.
46. Breeding LC, Dixon DL, Caughman WF. The curing potential of light-activated composite resin luting agents. J Prosthet Dent 1991;65:512–518.
47. Jefferies SR, Smith RL, Barkemeier WW, Gwinnett AJ. Comparison of surface smoothness of restorative resin materials. J Esthet Dent 1989;1:169–175.
48. Tjian AHL, Chan CA. The polishability of posterior composites. J Prosthet Dent 1989;61:138–146.
49. Schmid O, Krejci I, Lutz F. Ausarbeitung von adhäsiven zahnfarbenen Inlays aus Komposit und Keramik. Schweiz Monatsschr Zahnmed 1991;101:177–184.
50. Krejci I, Lutz F. Kompositfüllungen—das 1 X 1 des Ausarbeitens. Schweiz Monatsschr Zahnmed 1984;94:1015–1028.
51. Wirz J. Polierbarkeit gefraster Keramikinlays. Quintessenz 1992;43:1825–1834.
52. Itoh K, Iwaku M, Fusayama T. Effectiveness of glazing composite resin restorations. J Prosthet Dent 1981;45:606–613.
53. Torstenson B, Brannstrom M, Mattsson B. A new method for sealing composite resin contraction gaps in lined cavities. J Dent Res 1985;64:450–453.
54. Barnes CE. Mechanism of vinyl polymerization. I. Role of oxygen. J Am Chem Soc 1945;67:217–220.
55. Ruyter IE. Unpolymerized surfaces layers on sealants. Acta Odontol Scand 1981;39:27–32.