Reducing marginal leakage:  
a review of materials and techniques

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Although significant progress has been made in reducing the problem of marginal leakage, methods must be found to reduce the interface gap between the restoration and the tooth. The development of hydrophobic composites may reduce or eliminate marginal leakage even in the absence of chemical bonding.

The efficacy of restorative materials to seal cavity margins against the entrance of salivary constituents has been of interest to dental researchers for some time. As early as 1933, Fish showed that normal dentin would permit the penetration of dyes into the dentinal tubules of human teeth. A review of later studies related to microleakage shows that tooth structure is permeable to the diffusion of fluids through natural and acquired defects. Although the enamel surface contains natural cracks and lamellas that permit penetration of fluids, the enamel may also have areas of hypocalcification, hypoplasia, chemical dissolution, abrasion, and carious lesions that increase the potential for penetration. Dentin, however, permits transport of fluids through odontoblastic processes. Cutting dentin with a dental bur increases the surface area exposed and thus increases the number of tubules available for transfer of fluids to the pulp chamber.

Many techniques have been developed to evaluate permeability at the interface of the tooth and the dental restoration. These studies emphasize that the margins of restorations are not fixed, inert, and impenetrable borders but rather are “dynamic microcrevices which contain a busy traffic of ions and molecules.” With the advent of new composite resins, pit and fissure sealants, silver amalgam alloys, and new methods for closely adapting these restorative materials to enamel surfaces and cavity walls, marginal leakage can now be reduced to a minimum.

Although ionic charge and chemical reactivity of diffusing fluids contribute to marginal leakage, the physical and chemical nature of restorative materials, and the clinical skills of the operator are equally important. Since the publication of a review of microleakage in 1972, development of new restorative materials and clinical techniques to seal cavosurface margins has progressed at a faster rate than development of new methods for research for quantitating the diffusion of fluids associated with the phenomenon of microleakage.

The recent emphasis in restorative dentistry on prevention through control of plaque and sugar may also be a significant factor in lessening the negative effects associated with faulty margins. Although marginal leakage has not been readily identified with prevention, the clinician must appreciate that restorative procedures done well, in a healthy environment, are an integral part of prevention.

New dental materials and techniques, as well as new methods of analysis and diagnosis, may eventually offer the opportunity to eliminate marginal leakage around dental restorations. This paper reviews those materials and techniques that the dentist can use currently to reduce marginal leakage and thus promote clinical excellence.

Composite materials

The supreme test of a filling is its ability to maintain an unfailling margin. Composite resin restorations are the first in the class of tooth-colored materials to maintain marginal integrity during a clinically acceptable period. The characteristic brown ring around dental silicate and unfilled resin restorations was indicative of marginal leakage and accumulation of stained debris between the cavity wall and the restorative material. Marginal staining to this degree is no longer indigenous to tooth-colored restorations fabricated with composite resin placed on conditioned enamel. Jordan and
co-workers\textsuperscript{17} commented that the rare occurrence of marginal staining constitutes direct clinical evidence that acid-conditioning of enamel margins enhances marginal seal through an interlocking relationship between resin tags and etched enamel microporosities. Low-viscosity resins that form tags on polymerization have been reported to penetrate enamel pores to depths of 20 to 50 \( \mu \)m.\textsuperscript{18,19} Buonocore\textsuperscript{20} suggested that there may be 30,000 to 40,000 prisms per square millimeter of enamel surface available for formation of tags. Therefore, acid-etching produces a significant increase in the amount of surface area available for resin bonding and enhances the potential for sealing margins. Studies of marginal leakage with dyes and radioactive tracers have corroborated this latter finding.\textsuperscript{21-25} Acid-etching, the application of a low-viscosity bonding agent, and the use of the rubber dam to maintain dryness should be routine procedures for all composite resin restorations.

\textbf{Cavity preparation}

To take full advantage of enamel conditioning and the capillary flow of low-viscosity bonding agents into acid-created pores, it is important to design the cavity site with a maximum amount of supported enamel. Jordan and associates\textsuperscript{17} thought that a chamfer shoulder should be prepared in the enamel adjacent to a fracture site and should extend 1 mm cervical to the defect. The chamfer shoulder involves approximately a half of the enamel thickness. This simple cavosurface preparation not only provides a well-defined margin to which composite resin can be more exactly finished but also affords marginal bulk of restorative material as well. The chamfer-shoulder preparation also exposes more reactive subsurface enamel to the effects of the acid and enhances the conditioning effect by exposing the more desirable prism ends.\textsuperscript{17}

Others\textsuperscript{26-29} have suggested preparing cavosurface margins in a variety of ways, such as butt joint, featheredge, right angle, no bevel, slight bevel, long bevel, saucer-shape, and round. Obviously, all of these suggestions cannot be applicable in every situation. Until many of the uncertainties associated with laboratory studies of dye tracers can be resolved, the preparation that best serves the quantity and quality of remaining enamel is the most prudent option. Sound biomechanical principles of preparation of cavities for composite resins may be adequately served through the simple, but important, method of conditioning reactive enamel of sufficient thickness.

Long-term clinical trials that demonstrate the results of various types of preparations for retaining composite restorations are sparse. The earliest, and perhaps the most common clinical technique used, did not include a conventional preparation of the cavity. Retention was achieved principally by acid-conditioning several millimeters of uncut enamel adjacent to the cavity. After a 60-second water wash to remove residual acid, and a 30-second air spray to dry, the bonding agent supplied by the manufacturer was applied, and the restoration was placed and finished in line with the natural contours of the tooth. Although this may be the most conservative approach to preparation of cavities, and is perhaps inadequate in some cases, it has provided clinically acceptable results many times. Unfortunately, the length of time these restorations would be retained was not totally predictable because of the unknown physical and chemical nature of the enamel rods and the uncertainty of the amount of enamel required. Those practitioners who have used acid-conditioning and composite resins for several years can more easily predict the amount of retention required for clinical success.

\textbf{Supplementary retention by pins}

When a severe deficiency exists in either the quantity or quality of enamel available for retaining composite restorations by acid-etching, the clinician must use other means to gain sufficient mechanical retention to ensure a long-term marginal seal. Supplementary retention by one or two well-placed pins is more conservative in saving vital tooth structure than cutting a cavity deeply into the dentin to provide retentive line and point angles. With the variety of pin sizes available and the simplicity of the procedure for achieving maximum retention at minimum depths, this method may also be biologically less harsh on the pulp than the removal of additional dentin to create a cavity that is sufficiently retentive.

Improper use of pins, like anything else in the practice of dentistry, can be hazardous. A good understanding of the morphology of the tooth, types of pins available, indications for the use of pins, and proper management of procedures preclude many of the problems so frequently attributed to use of pins. If the quantity or quality of enamel is questionable in any way, the practical approach should favor too much retention rather than too little. This can usually be best achieved when the size of pins and distance between pins are in correct relationship with the amount of tooth structure available and with the correct proximity to the dentinoenamel junction. Crazing or cracking of enamel and dentin is therefore minimized.

\textbf{New composite materials and techniques}

The development and improvement of composite restorative materials continue to be a viable area for dental research. New filler systems are being introduced that vary in particle size, type, and amount; new catalysts and new methods of physical activation have recently become available. The newest single component system is physically cured by visible light. This system consists of a resinous matrix composed of urethane dimethacrylate and ethylene glycol dimethacrylate comonomer heavily loaded with a silane-coated radiopaque glass particulate filler.\textsuperscript{30} The activator light used to polymerize this material\textsuperscript{*} is emitted from a quartz halogen lamp filtered to eliminate all but visible light. A long-term clinical evaluation of this single-component composite has not yet appeared in the literature to substantiate its clinical performance nor is a bonding agent currently being suggested for enhancing marginal seal.

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A new, chemically activated, two-component system has recently been introduced as a universal anteroposterior restorative that can, according to the manufacturer, surpass amalgam in sealing margins. The strontium glass filler reputedly resists wear and still provides a good esthetic appearance and a smooth finish. Results after three years of clinical testing\(^31\) suggest that this composite can resist erosive forces found in the posterior area of the mouth. An acid-etch procedure and a bonding agent are required to improve marginal seal, but no glaze is suggested to improve surface smoothness.

It is unfortunate that some new microfine resin systems that reputedly have high abrasion resistance and provide smooth surfaces, also provide softness (Barcol hardness), coefficients of thermal expansion as high as \(92 \times 10^{-6}\) ppm/C, decreased tensile strength, and increased water absorption and swelling. In the pursuit of enhanced clinical properties such as smoothness, the clinician should not accept other compromised properties that are vital to the long-term biologic welfare of the tooth. As expansion values have progressed from \(127 \times 10^{-6}\) ppm/C, with the unfilled resins of the past, to \(25 \times 10^{-6}\) ppm/C with many composite resins of the present, the clinician should not again accept high thermal expansion values. Increased marginal percolation, with subsequent diffusion of fluids through the dentin, would be potentially detrimental to pulp health.

**Hydrophilic vs hydrophobic**

All commercially available composite resins are hydrophilic in nature and readily absorb water and oral fluids. In the absence of chemical bonding of composite to tooth structure, any space between the cavity wall and the restorative material is spontaneously filled when brought into contact with water or saliva.\(^{32}33\) The development of experimental fluoromethacrylate composites that are hydrophobic, and thus absorb minimal amounts of water or saliva, provides the opportunity to reduce or eliminate marginal leakage even in the absence of chemical bonding.\(^32\) The content of fluorocarbon in the experimental composite exercises a profound change in its properties with respect to water.\(^32\)33

Although the hydrophobicity of a composite resin is important to the potential reduction or elimination of marginal leakage for any class of restoration, it may have greater clinical significance for composite resins that are used as foundations or core buildups. The fact that all composite core buildups for crown and bridge restorations have been fabricated with hydrophilic composite materials may explain a recent finding\(^34\) that the average life of a full veneer crown was between two and three years; the average bridge lasted three to four years before replacement was necessary. Perhaps many of these premature failures resulted from early loss of the luting media. As it is generally accepted that abutment teeth must be clinically dry during the luting of cast restorations, this may be impossible to achieve over composite core buildups that are saturated with oral fluids and unreacted free monomer. If a luting cement such as zinc phosphate is not protected from moisture during setting, phosphoric acid is leached out and leaves the cement chalky and permeable.\(^35\) Initial solubility is largely phosphate and a small amount of zinc, and zinc continues to be leached out at a constant rate. The clinical permanence of zinc phosphate cement is, therefore, strongly linked to the factors of solubility and disintegration.\(^35\) Future hydrophobic composites should be better materials for core buildups, as they would not absorb water or oral fluids. The luting strength of zinc phosphate cement should thus be enhanced on those surfaces that are adequately dried, and the clinical life of cast gold restorations should, therefore, be increased.

Whereas new fluoromethacrylate composites will be hydrophobic,\(^32\)33\) it is important to realize that silver amalgam is already hydrophobic and, as such, rejects absorption of oral fluids. As a core material for crown and bridge abutments, it has not yet been surpassed. Dimensional change is minimal, and hardness and strength are superior to composite resin.

**Silver amalgam restorations**

The clinician can influence the degree of marginal leakage by placing the rubber dam, cutting retentive cavities with refined cavosurface margins, selecting proper bases and liners, wedging and reinforcing the matrix, using adequate mixing and condensation procedures, and placing pins when additional retention to or reinforcement of remaining tooth structure are needed. Although all of these procedures are important to the success of the amalgam restoration, those that best control marginal leakage are the application of two coats of copal resin varnish to all surfaces of the cavity, including cavosurface margins; the use of pins placed at least 0.5 to 1.0 mm inside the dentinoenamel junction; and the adequate trituration and condensation of alloys having setting times commensurate with the size and complexity of the defect being restored, especially when pins are involved.

Use of varnish liners reduces marginal leakage caused by expansion and contraction of the alloy in setting.\(^36\) The application of varnish will eliminate potential irritation of the pulp and postoperative sensitivity.

Properly placed pins provide additional retention and stability of the restoration within the cavity, as well as reinforcement of the remaining tooth structure through cross-splinting. These factors enhance the marginal integrity of the restoration as it functions over time.

As the quality of an amalgam restoration depends largely on its adaptation to cavity walls, the condensation of most silver amalgam alloys requires a firm, disciplined stepping force; each increment must be bonded to the mass already placed. To decrease voids and improve adaptation, relatively small increments should be inserted during condensation. To assure minimal residual mercury and maximal strength, the force of condensation should be as great as possible, consistent with the comfort of the patient.\(^37\) Research may soon provide an electronic device for monitoring condensation pressures, so that the optimal force for condensing various alloy types
can be learned and controlled. Without mechanisms for measurement, the student has no controllable method to evaluate and improve his skill. 36 The cliche "firm, disciplined pressure" could then become more exact and reproducible. Periodic monitoring of the condensing force of each clinician could supply meaningful information and broaden the scientific rationale relative to the nature of the forces being applied.

As silver amalgam restorations age with time and function, the interface between the alloy and tooth structure seals itself with corrosion products (tin oxides) that minimize leakage. 42,39 Thus amalgam restorations have been characterized as improving with age, whereas the margins of other restorations such as cast gold decline through solubility of the luting media.

**Cast gold restorations**

Prime 46 asked in 1937: "How long will dentists fill a cavity with cement and call it temporary— camouflage it by pressing a gold casting into it and call it permanent?" Poorly adapted margins or excessive use of cement predispose cast gold restorations to marginal leakage, dissolution of the luting cement, recurrent caries, and involvement of the pulp. The vulnerability of the pulp to salivary contaminants frequently leads to degenerative changes or carious exposure.

The removal of cast gold restorations for inspecting and repairing marginal defects and supportive walls of dentin compromised by recurrent caries usually requires at least cervical extension of the preparation and the fabrication of new castings. An alternative to such a minimal modification of the remaining tooth structure is to rebuild the tooth with a pin-retained amalgam core that will properly support the casting. This method guarantees a hard, hydrophobic, cross-splitlined, self-sealing foundation that is retentive and provides the anatomically correct crown-root ratio. In combination with the final cemented casting, a double seal is formed against marginal leakage.

Before each abutment tooth is rebuilt with pins and amalgam, all restorations and cement bases, regardless of age or appearance, should be removed to assess the condition of remaining dentin. This prevents concealment of unknown problems that will later be a source of concern and confusion. Cavity defects that have less than 2 mm of remaining dentin must be covered with a neutral or calcium hydroxide base to allow reparative dentin to form. A secondary base can be placed over the primary base for its sedative and reinforcing effect, if desired. The deep cavity not only requires palliation of the injured pulp but also protection from thermal insults, galvanic shock, mechanical trauma, toxic ingredients, and microleakage. Placing damaged pulps at rest for appropriate healing periods is best provided by properly based and lined silver amalgam foundations retained by pins. 40 Crown preparations with ideal retention, anatomy, and occlusal clearance can then be cut and reproduced in cast gold over healed, comfortable teeth. The patient's postoperative discomfort after major reconstructive therapy can thus be minimized. The clinician should never assume that postoperative discomfort does not exist simply because the patient fails to complain. 41

The surest marginal seal achieved with cast gold (other than over a silver amalgam foundation) is accomplished with wax patterns that are water-swaged and castings that are vise-fit and burnished to a hard die. This technique provides margins similar to those of gold foil. 42 As such, they are less liable to leakage, dissolution of the luting cement, and postoperative sensitivity.

**Direct gold restorations**

No greater mistake can be made than to think a filling is good simply because it is made of gold foil. 16 If a proximal wall is being replaced, as with Class II restorations, a reinforced, unyielding matrix should be used to improve the density of the foil during carefully controlled condensation pressures. The matrix will also assist in recreating normal tooth contours and contact points and ensure the best possible marginal seal at the gingival and proximal walls. The reinforced matrix is unfortunately overlooked with most amalgams, perhaps because less pressure is required to condense amalgam increments than to cold-weld gold foil pellets for close adaptation to cavity margins.

Adequate retention for gold foil in a large Class V defect caused by severe erosion is difficult to achieve without use of supplementary pins. Retention by other means would require the sacrifice of too much additional tooth structure. As the lateral walls of a Class V preparation normally provide four-wall stabilization of the gold during condensation, a pin placed on each side of the pulp chamber substitutes for the missing lateral walls.

For superior marginal integrity that will last for long periods, compacted gold restorations require well-planed enamel margins, good retention, disciplined condensation at adequate pressure and frequency, and proper finishing and burnishing of all margins. Placing gold foil by hand pressure alone usually fails to provide the density, condensation discipline, hardness, and close adaptation to the cavity walls required for a lasting marginal seal. Gold foil depends on close adaptation to tooth structure and cohesion between gold particles for maximum retention, stability, and sealing properties.

**Future methods of analysis**

Although neutron activation analysis 44,45 provided a quantitative method for assessing the marginal seal of dental restorations placed and maintained in vivo for varying functional periods, the expense, complexity, and sensitivity of the method diminished its practicality for analysis of microleakage. Chairside replication of restored teeth for direct observation with the scanning electron microscope (SEM) 46-51 has also been used to demonstrate marginal defects and to follow changes in the size of the defects on a longitudinal basis. As replica techniques do not change the structures being evaluated, replicas may be repeated many times at selected intervals. Shrinkage and other artifacts usually associated with preparation of biologic tissue for SEM examination is avoided with replicas.

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developed a conductimetric technique to measure changes in the dimensions of the cavity wall-restoration interspace with use of an electrochemical cell. Other methods for monitoring marginal leakage quantitatively for long periods will undoubtedly be described in the future and should be superior to commonly known methods.

Dental problems that have depended largely on clinical judgment for explanation and solution are more recently being studied with sophisticated electronic gadgetry. For example, an electrical resistance-measuring instrument detects early occlusal carious lesions; the Periotron determines the degree of gingival inflammation relative to the rate of flow of crevicular fluid in the gingival crevice; locators of the apical foramen assist the endodontist in better sealing of the apexes of teeth during root canal therapy; the Reflectometer comparatively evaluates the abrasiveness of toothpaste, powder, and toothbrush bristles in vivo; a moisture-sensing device indicates the relative wetness of enamel and dentin surfaces; and a dental pulp stethoscope can discriminate between levels of dental hypersensitivity. With this trend toward electronic devices for diagnosing, measuring, and monitoring incipient levels of dental-related problems, it may also be possible for the width and depth of marginal discrepancies around dental restorations to be electronically measured in vivo and the amount projected quantitatively on a digital read-out screen. This more objective device should permit greater experimental reproducibility than the dyes and radioactive tracers still in use.

**Summary**

Although significant progress has been made with the advent of composite restorative materials and associated techniques, the problem of marginal leakage has been lessened but not solved. The primary aim of future work must still be directed toward preventing the formation of a gap between the restoration and the tooth.

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*Fotofil, Johnson & Johnson, East Windsor, NJ 08520.†Profile, S. S. White Dental Products, Philadelphia, 19102.‡Harco Electronics Ltd., Winnipeg, Canada R3H 0M1.§Monsanto Co., St. Louis, 63166.

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Mosaic depiction of the microscopic structure of enamel. Photograph by Dr. Harry Cimring, Beverly Hills, Calif. The photograph was taken at the UCLA School of Dentistry.