Adhesive liner incorporation in dental amalgam restorations

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Abstract *Previous studies have indicated that adhesive liners can affect the mechanical properties of set amalgam and, therefore, may become incorporated within the amalgam. The purpose of this in vitro study was to determine the distribution of two adhesive liners within standardized Class I amalgam restorations. Cavity preparations were restored with dental amalgam or with dental amalgam and either of two adhesive liners. Thin sections were cut from the restored teeth in various planes and examined radiographically and with a reflecting microscope. Radiographs were digitized and computer enhanced for improved observation. Amalgam restorations placed with adhesive liner had greater amounts of nonamalgam substance than did the nonadhesive liner restorations. Both Amalgambond Plus and Resinomer used with All-Bond II were capable of becoming incorporated within the body of a Class I restoration placed with a standard restorative amalgam bonding technique.* (Quintessence Int *1997;28:49-55.*)

Clinical relevance

Adhesive resin liners may become incorporated within the body of an amalgam restoration. This incorporation can affect the amalgam's mechanical properties and may affect clinical performance.

Introduction

Almost two thirds of practicing dentists[1] currently use amalgam bonding in an effort to decrease microleakage, decrease secondary caries at restoration margins, increase the strength of the restored tooth, and decrease postoperative sensitivity.[1,2] Currently available bonding materials include both resin and resin-glass-ionomer cement combinations.[1] Some studies have indicated that these bonding systems are very technique sensitive, resulting in variations in the bond strength[3] and the film thickness of the bonding agent.[4] The type of dental amalgam used also affects bond strength.[5]

The inclusion of porosities within dental amalgam restorations affects mechanical properties, and the inclusion depends on certain technique factors.[6-10] Factors known to affect the number, size, and/or distribution of porosities in dental amalgam include the size of the condenser, the force of condensation, the choice of dental amalgam, the size of the increment, and the geometry of the preparation. Because dental amalgam must be sufficiently strong to resist fracture intraorally, where it is subjected to complex forces, material and technique factors must be optimized to provide the best clinical performance.

Two in vitro studies have demonstrated that resin adhesive liners affect the mechanical properties of set amalgam, although with variable results. One study[11] has demonstrated that adhesive resin incorporated into hand-condensed spherical dental amalgam alloy significantly reduces the compressive strength of the alloy, measured at 1 hour, 24 hours, and 7 days. Relatively large standard deviations, ranging from approximately 10% to more than 50% of the group mean for compressive strength were reported, consistent with considerable technique sensitivity. This

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same study demonstrated the presence of the adhesive resin within the dental amalgam restoration but did not show its distribution within the restoration.

Another in vitro study[12] demonstrated a significant reduction in diametral tensile strength of dental amalgam condensed into a cavity containing an excess of either of two resin adhesives. The compressive strength was not affected by the use of adhesive resin. Although the authors stated that resin was not restricted to the preparation walls, because of the effective mixing of resin within the dental amalgam during condensation, they did not show resin within the dental amalgam restoration.

Because adhesive resin liners become incorporated into dental amalgam and thereby affect its mechanical properties, and because these changed mechanical properties are variable and partially dependent on technique factors, the present study was planned to determine the distribution of adhesive resin liners within dental amalgam restorations. Confirmation of and knowledge about this distribution could lead to improved and more consistent mechanical properties for these restorations and possibly to improved clinical performance. Therefore, the purpose of this study was to determine the distribution of two adhesive liners within standardized Class I dental amalgam restorations, in vitro, by using thin-section radiography and reflecting microscopy.

Method and materials

Preparation of control specimens

Two freshly extracted, noncarious human maxillary third molars were mounted in individual stone bases. The occlusal surfaces of the molars were ground flat and perpendicular to the long axis of the tooth with the fine wheel of an orthodontic model trimmer operating with continuous water lubrication. The flattened occlusal surface provided a uniform surface for standardizing the preparation depth and for standardizing the amalgam-carving technique.

Standardized occlusal cavities were prepared in each tooth. A 4 × 6-mm rectangle was drawn in the middle of the ground occlusal surface with a ruler and fine pencil. The tooth and stone mount were placed in a paralleling and milling device (JM Ney), which maintained the ground surface perpendicular to the long axis of a No. 245 friction grip dental bur in a high-speed handpiece (KaVo No. 625C) that was mounted in the paralleling and milling device. The No. 245 bur, operated at full speed and with continuous water lubrication, was lowered into the occlusal surface to a depth of 3.0 mm. This depth was maintained by locking the handpiece into position. The preparation was extended to the pencil-line borders by hand manipulation of the tooth and stone mount within the paralleling device. The result was a 4 × 6 × 3-mm cavity preparation with a flat pulpal wall, smooth and flat lateral walls that were slightly convergent occlusally in the pulpal half of the wall, a 90-degree cavosurface angle, and slightly rounded internal line angles. The cavosurface margins of both preparations were entirely in dentin.

Each preparation was cleansed with a 10-second air-water spray from a triple syringe and air dried. The teeth were restored with amalgam. Regular set two-spill amalgam capsules (Dispersalloy, Caulk/Dentsply) were triturated for 7 seconds in a high-speed amalgamator (Silamat, Vivadent). Amalgam was condensed into the cavities in three increments with a 2.03-mm-diameter round, smooth, flat-ended condenser (Oregon No. 4, Thompson Dental), used with 2 to 3 lbs of force per thrust. The surface of the amalgam was burnished and carved flush with the surface of the tooth.

Styrene beads, 250 μm in diameter, with a standard deviation of 149 to 350 μm (Bangs Laboratories), were placed in one of the cavities before it was restored with amalgam. A volumetric scoop was used to place 11.7 mm^3 of beads on the pulpal floor. The beads were then incorporated into the amalgam during condensation.

The specimens were stored in tap water at room temperature for 1 week prior to sectioning.

Preparation of experimental specimens

Five freshly extracted, noncarious human maxillary third molars were mounted and prepared with rectangular cavities as described for the control specimens. Each experimental specimen was restored with amalgam, as previously described, using the amalgam bonding systems listed in Table 1. The manufacturer's directions were followed for each product.

Sectioning of specimens

The crown portions were cut off, and the teeth were placed in a new stone mount. Each crown was oriented to provide sections either perpendicular (horizontal sections) or parallel (vertical sections) to the long axis of the tooth (Table 2). A water-cooled diamond blade (Leco 801-137) in a thin-section saw (Bronwill

Table 1 Bonding materials utilized

Specimen No.	Material	Manufacturer	Lot No.
1	None		
2, 3	Amalgambond Plus	Parkell	Adhesive agent: 4191403 Base B: 40903 Catalyst C: 4100 71 Dentin activator: 41001 HPA: 40603
4, 5, 6	All-Bond 2/Resinomer	Bisco Dental	All-Bond 2: 069154 Resinomer: 129134
7	None (styrene beads)		

Table 2 Summary of sections

Section No.	Specimen No.	Bonding agent	Section plane	Section location
1	1	None	Vertical	Center
2	1	None	Vertical	Lateral
3	2	Amalgambond Plus	Horizontal	Occlusal
4	2	Amalgambond Plus	Horizontal	Center
5	2	Amalgambond Plus	Horizontal	Pulpal
6	4	All-Bond 2/Resinomer	Horizontal	Occlusal
7	6	All-Bond 2/Resinomer	Vertical	Center
8	5	All-Bond 2/Resinomer	Vertical	Lateral
9	3	Amalgambond Plus	Vertical	Lateral
10	5	All-Bond 2/Resinomer	Vertical	Center
11	3	Amalgambond Plus	Vertical	Center
12	4	All-Bond 2/Resinomer	Horizontal	Center
13	4	All-Bond 2/Resinomer	Horizontal	Pulpal
14	6	All-Bond 2/Resinomer	Vertical	Lateral
15	7	None (styrene beads)	Vertical	Center
16	7	None (styrene beads)	Vertical	Lateral

GH-4) was used to cut sections of approximately 400 to 450 μm. Each section was thinned by hand with progressively finer 320-, 600-, and 1500-grit carborundum papers to a thickness of 190 ± 5 μm. The thinned sections were washed in tap water, blotted dry on absorbent paper, and stored dry.

Radiography and digital imaging

Radiographs of the thinned sections were made using video-imaging film (Cronex MRF 33, DuPont) exposed at 100 KV(p) and 10 mA for 3 seconds with a source-to-object distance of 12 inches (Gendex GX1000). The films were developed by hand in deep tanks with developer and fixer, diluted 1:1 (Peri-Pro chemistry, Air Techniques), at 72°F for 3.5 minutes of development, 4 minutes of fixation, and 15 minutes of wash time. The films were air dried and individually mounted.

Each radiograph was digitized for enhancement and visualization to determine the distribution of radiolucencies within the amalgam sections. A black-andwhite charge-coupled device camera (JVC No. TK-S310, Victor) equipped with a 55-mm macro lens (Micro-NIKKOR-P, Nikon) captured the film image. The video signal was digitized in 8-bit grayscale, at a resolution of 640 × 480 pixels, with a digitizing board (Scion LG-3) in a personal computer (Macintosh IIsi, Apple) that was running an image capture and analysis software program (NIH image 1.55, Wayne Rasband, US National Institutes of Health). The digital images were stored as TIFF files and viewed on a 19-inch, high-resolution monitor (Raster Ops Model CM2086 A3UX) in 8-bit grayscale. Each image was enhanced by optimizing the contrast and brightness of the specimen portion of the image field with the "enhance contrast" function of the imaging software. Dimensions were determined by calibrating the digitized images from known distances on the actual specimens.

Laser prints (Laserwriter Pro, Apple) were made of selected images. The laser prints were photographed for publication.

Staining of sections

To differentiate air voids from bonding material incorporated in the amalgam sections, each section was stained with a 2% solution of Oil Red O (Sigma Chemical) in xylene for 15 minutes. Stained sections were agitated in xylene for 15 seconds to remove excess dye solution and air dried.

Microscopy

The cut surface of each section was observed under a reflecting microscope (Vanox, Olympus) at ×50 magnification to determine the distribution of nonreflective areas on the surface. Dimensions were determined with a 0.01-mm objective micrometer (Olympus). Specimens were photographed at ×50 magnification (5052 TMK Film, Eastman Kodak) and full-frame 4 × 5-inch images were produced (Polycontrast III RC paper, Eastman Kodak) for further analysis.

Results

Control (no bonding agent)

Radiographs of vertical sections taken throughout the restoration revealed three to six widely dispersed radiolucencies 0.05 to 0.06 mm in diameter. The largest radiolucency, measuring 0.10 × 0.35 mm was in a section taken from the center of the restoration and was oriented approximately parallel to the occlusal surface and 1.00 mm from the occlusal surface. In the same section, another radiolucency, 0.15 mm in diameter, was adjacent to the vertical wall. There were no radiolucencies at the occlusal surface. The largest dimension of any of the radiolucencies was 0.35 mm. Except for a 0.10 × 0.35-mm radiolucency in one section, adaptation of amalgam to the cavity wall was apparently complete.

The reflecting microscope revealed approximately 20 to 25 widely dispersed, non–dye-stained nonreflective areas, 0.05 mm in diameter, in each section. There were no nonreflective areas at the occlusal surface, and there was no discernible pattern of nonreflective areas.

Control (with styrene beads)

In the radiograph of each vertical section were approximately 25 to 50 round radiolucent areas, measuring 0.12 to 0.28 mm. These were confined to the pulpal half of the restoration. The majority of the radiolucent circles 0.20 mm or less in diameter were of intermediate radiolucency, consistent with sectioning of spheres into unequal portions.

The reflecting microscope, at ×50 magnification, revealed that there were multiple red dye–stained nonreflective circles, 0.12 to 0.24 mm in diameter, in the pulpal half of the restoration. One irregular unstained nonreflective area, 0.12 × 0.12 mm, was the largest such fault found in these sections. There were approximately 25 to 50 well-dispersed, unstained nonreflective areas, 0.03 mm in diameter, in each section.

Amalgambond Plus restorations

Radiographs of vertical sections demonstrated radiolucent veins, 3.00 mm in length and less than 0.04 mm wide, approximately 1.00 mm from and parallel to the pulpal wall. In one section, an irregular radiolucent vein, less than 0.04 mm wide, extended from the central portion of the restoration to the occlusal surface at the cavosurface of the lateral wall. In the same vertical section, a radiolucent area was also observed at the cavosurface of the lateral wall, extending approximately 0.12 mm in width and 0.24 mm occlusopulpally to the occlusal surface of the restoration (Fig 1).

The radiograph of a horizontal section taken from the occlusal portion of the restoration was free of radiolucencies, except for a 0.40-mm radiolucent vein, approximately 0.04 mm in width, extending obliquely from a corner of the restoration into the body of the

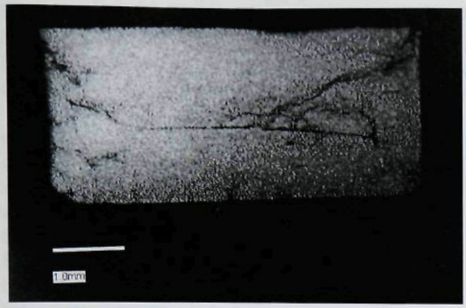

Fig 1 Digitized radiograph of a vertical section taken near the lateral wall of the restoration from specimen 3, which was restored with Amalgambond Plus. One major thin vein extends across the restoration, approximately parallel to the pulpal floor. A second vein extends from the central portion of the restoration obliquely toward the lateral wall. Note the extension of one vein to the occlusal surface near the cavosurface margin.

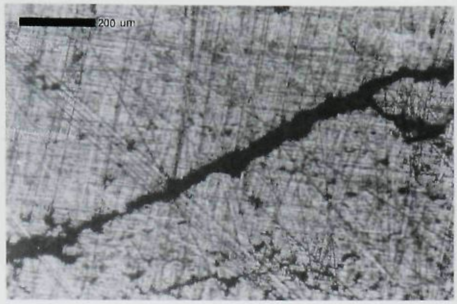

Fig 2 Reflecting microscopic image of a vertical section taken near the lateral wall of the restoration from the same section shown in Fig 1. The finer features of the nonreflective vein can be seen, along with multiple smaller adjacent, but discontinuous, irregular nonreflective areas. Note the variation in the width of the vein.

restoration. The radiograph from a similar section made from the pulpal portion of the restoration was free of radiolucencies.

In the reflecting microscope, a vertical section taken from the lateral portion of the restoration contained a continuous, oblique, red dye-stained nonreflective vein, 0.06 to 0.01 mm wide. A smaller red dye-stained nonreflective vein joined this one in the center of the section. Multiple adjacent, but discontinuous, irregular red dye-stained nonreflective areas, 0.03 to 0.15 mm across, were within 0.50 mm of the larger vein (Fig 2).

Resinomer/All-Bond 2 restorations

Radiographs of horizontal sections from the occlusal portion of the restoration were free of radiolucencies, except for several diffuse, poorly defined areas in the body of the restoration located within the 1.00-mm periphery. Radiographs of horizontal sections taken from the pulpal portion of the restoration contained several radiolucent veins, 0.50 to 1.00 mm in length and 0.04 to 0.08 mm in width, extending from the cavity wall toward the center of the restoration. Several less well-demarcated, irregular radiolucencies, 0.25 × 1.00 mm, were in the center of the restoration in these same radiographs, along with one well-demarcated 0.50 × 0.08-mm radiolucent vein. In the radiograph from a horizontal section taken from the center of the restoration was a continuous circumferential radiolucent vein, roughly paralleling the lateral boundary of the restoration and 0.04 to 0.50 mm from the boundary. An irregular radiolucency, 0.40 × 0.80 mm, which was continuous with the circumferential radiolucent vein, also was found. In addition, several isolated distinct radiolucencies, 0.08 × 0.12 mm, were found within the body of the restoration (Fig 3).

Radiographs of vertical sections revealed multiple, distinct radiolucent veins, 0.02 to 0.04 mm in width, located roughly parallel to the pulpal floor of the restoration and extending from one lateral wall to the opposite wall. A typical vein was composed of line segments, 1.00 to 1.25 mm in length, connected in an overlapping and branching pattern. Two such major veins divided the restoration into three roughly equal portions (Fig 4).

The reflecting microscope, at ×50 magnification, showed red dye-stained nonreflective veins, 0.02 mm to 0.03 mm in width, in a pattern similar to the radiographic images from vertical sections. Additionally, multiple red dye-stained nonreflective areas, 0.01 × 0.01 mm to 0.03 × 0.10 mm, were associated with the larger veins but distinct from them (Fig 5). A vertical section taken from the middle of the restoration showed a 0.06-mm-wide, red dye-stained, nonreflective vein at the occlusal surface, adjacent to the

Fig 3 Digitized radiograph of a horizontal section taken from the middle of the restoration from specimen 4, which was restored with All-Bond II and Resinomer. A circumferential radiolucent vein roughly parallels the lateral walls. Wider radiolucent areas are also associated with this vein and adjacent to the lateral border of the restoration.

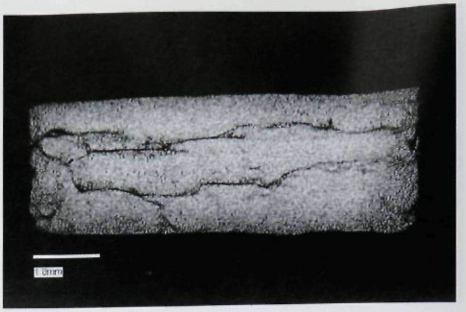

Fig 4 Digitized radiograph of a vertical section taken from the middle of the restoration from specimen 6, which was restored with All-Bond II and Resinomer. Two typical veins, composed of line segments 1.0 to 1.25 mm in length, are connected in an overlapping and branching pattern. These two veins appear to divide the section into three approximately equal portions.

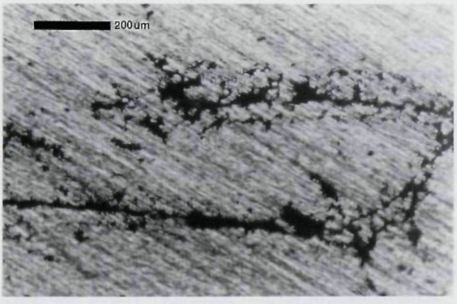

Fig 5 Reflecting microscopic image taken from the same section shown in Fig 4. The finer detail of one of the line segments from the major vein can be appreciated. Smaller nonreflective areas are associated with this vein. These smaller areas are not continuous with the vein.

cavosurface of the preparation. In a horizontal section taken from the center of the restoration, a relatively dense and irregular pattern of red dye-stained nonreflective areas were within 0.50 mm of the tooth-restoration interface. Individual defects in this area measured 0.01 to 0.10 mm across.

Discussion

The relatively small and randomly dispersed nondye-stained air voids observed in the unbonded control restorations did not appear to be related to the incremental additions of amalgam during condensation. Apparently, the 2 to 3 lbs of force per thrust during condensation, applied with the 2.03-mm flat-ended condenser, can result in air voids within the restoration, as found in earlier studies.[7,9] These voids also were found in the unbonded control restorations containing the styrene beads.

Because the dye-staining technique was able to differentiate between air voids and inclusion of bonding material, some defects in the bonded specimens were identified as air inclusions. However, these air inclusions were minimal compared to the inclusion of bonding material and were consistent with the number and distribution of those found in the control sections. The radiographic shape and density of the defects in the restorations containing styrene beads, and their appearance microscopically, indicated that nonamalgam, nonair inclusions could be detected by these methods.

The major inclusions of bonding material in all specimens appeared to be oriented in irregular sheets, roughly parallel to the pulpal floor of the restoration, and extending throughout the mesiodistal and buccolingual dimensions of the restoration. These irregular sheets appeared to correspond to the incremental placement of amalgam during restoration. In some instances, these sheets intersected and connected, possibly because of normal variations in the initial manipulation of each amalgam increment during condensation. The smaller, well-dispersed areas of inclusion found in most sections usually appeared to be distinct from the main veins and incorporated over a broader area of the section, up to 2.00 mm away from the main veins.

This pattern of irregular sheets and broadly dispersed smaller inclusions could contribute to the decrease in bonded dental amalgam properties that was previously reported[11,12] and could result in bonded amalgam restorations that behave anisotropically, although this was not confirmed by the present study. Because of the well-dispersed interface between bonding material and amalgam within the restoration, and the actual inclusion of bonding material within the restoration, these restorations could be considered composite structures with physical properties unlike those of either dental amalgam or the bonding materials.

Summary

In this study, all restorations had areas of incorporation of nonamalgam substance, from air voids, inclusion of bonding material, or both. The bonded amalgam restorations contained greater amounts of nonamalgam substance than did the unbonded restorations. In vertical sections of the bonded restorations, areas of incorporation of nonamalgam substance appeared to correspond to the three incremental additions of amalgam placed during the restoration of each cavity. This incremental pattern was not apparent in the horizontal sections of the bonded restorations. Horizontal sections taken at the occlusal surface of the bonded restorations were relatively free of nonamalgam defects; however, there was a nonamalgam defect at the cavosurface margin extending to the occlusal surface in a vertical section of one restoration. Areas of air or adhesive liner incorporation found within the restorations in this study varied in size from 0.40 × 0.80 mm to 0.01 × 0.01 mm.

Both Amalgambond Plus and Resinomer with All-Bond II were capable of becoming incorporated within the body of a Class I restoration placed with a standard restorative amalgam bonding technique. The pattern of incorporation corresponded to incremental amalgam placement during restoration. Amalgam bonding material was found at the cavosurface of the restoration and extended to the occlusal surface of the restoration. Further study is necessary to better understand the pattern of distribution of bonding materials within bonded amalgam restorations, to correlate these patterns with physical properties, and to determine the effects of restorative technique on inclusion patterns and physical properties.

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