NATIONAL BUREAU OF STANDARDS REPORT

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Progress Report
on

AMALGAM, CEMENTS AND ESTHETIC RESTORATIVES: SOME NEW DEVELOPMENTS

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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AMALGAM, CEMENTS AND ESTHETIC RESTORATIVES: SOME NEW DEVELOPMENTS

by
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AMALGAM, CEMENTS AND ESTHETIC RESTORATIVES: SOME NEW DEVELOPMENTS

Nelson W. Rupp, D.D.S.

Over 80% of a general dentist's treatment procedures involve the selection and manipulation of materials. As the result of research new materials and techniques are continuously being developed and these innovations stimulate quite convincing claims by both dentists and manufacturers. Often this enthusiasm for the new is well founded but on occasion the dentist who adopts them learns to his dismay that the conclusions to use the materials or technique were not based upon sound evidence. An example was the almost universal acceptance followed by nearly total rejection of unfilled resin as a replacement for silicate cement. This loss of favor continues today even though the resin manufacturers have improved the color stability and modified the handling techniques which compensate for the undesirable physical properties.

There are several sources of information available to dentists regarding new materials. The American Dental Association supports two laboratories. One is in the Chicago office of the American Dental Association and the other is in the National Bureau of Standards at Washington, D. C.

In addition, the ADA, as the need arises, requests an individual or a laboratory to evaluate a material or technique. Two such instances where consultants prepared reports occurred recently. Dr. Myers of the University of Michigan prepared a literature review of zinc oxide-eugenol cements for the Council on Dental Materials and Devices.[1] Professor Swartz at Indiana University prepared for the Council on Dental Research a report which was titled "Research in Dental Materials".[2] Both reports were published in the Journal of the American Dental Association. The Council on Dental Materials and Devices of the ADA occasionally prepares position statements for publication in the JADA as new materials and techniques are introduced. This is illustrated by a report in the past year on fissure sealants.[3] In addition to these current and timely articles the Council on Dental Materials and Devices publishes biannually a book "Guide to Dental Materials and Devices".[4] Each member of the ADA is supporting these services and has access to the current information through the JADA.

The following discussion will include new developments in restorative materials, dental amalgam, cements, esthetic restorative materials and fissure sealants.

Dental Amalgam

Each year approximately 160 million amalgam restorations are placed.[5] This is approximately 80% of all single tooth restorations. Consequently, it is easy to understand why the manufacturers of composite resins are eager to replace the conventional dental amalgam. Until the results of rigorous clinical studies are more convincing, however, dental amalgam, along with gold, will remain the choice for load-bearing areas on posterior teeth. The amalgam restoration should be recognized as the dentist's best friend because a well-condensed, contoured and polished amalgam will be acceptable esthetically as well as functional for many years.

The results of a clinical study made by the author in which the reasons for placing restorations were recorded are shown in Table 1. This is unpublished data which was observed in 1958. The study was prompted by a feeling that a large percentage of time was spent in repeating prior treatments. Two categories, new and replacements, were selected to identify the reason for the restoration. Of the 424 restorations, 119, or 28%, were replacements. This study was completed prior to the plaque control era. Consequently many replacements, both material failure or marginal breakdown, were attributed to faulty cavity preparation or improper handling of the material rather than the lack of patient's education or motivation to prevent plaque buildup. The record verified the feeling that considerably more treatment could be done if the failures could be reduced.

Current research strongly indicates that corrosion and its aftermath, pitting and marginal breakdown, are the principal causes of amalgam failure.[6] Along with this, however, is the dynamic flow or creep and the resultant extrusion of the amalgam from the cavity.[7] These two factors combined with inadequate bulk at the cavosurface margin are believed to be directly involved in the majority of cases involving marginal breakdown and secondary caries. A typical example of such a failure is shown in Figure 1.

The following contributions to amalgam failure are within the operator's control: (1) Inadequate amalgam bulk at the cavosurface margin. (2) Failure to establish correct occlusal contact. (3) Fracture of enamel at the cavosurface margin. (4) Amalgam, either condensed into an acute cavosurface angle or carved to a thin edge. (5) Condensation of amalgam too long after trituration. (6) Improper compaction and finish of the amalgam restoration.

The best way to tie all of the procedure together in one package is to start with the preparation of the cavity and to discuss each step separately.

Cavity preparation

Often there will be fractured enamel rods remaining at the cavosurface margin following the use of ultraspeed rotary instruments. These loosened rods are planed away with hand instruments or more slowly revolving burs. The margin is finished as nearly as possible to a 90° angle, being certain to leave no unsupported enamel rods. This ensures maximum bulk of amalgam and enamel at the margin and permits a thorough condensation. There are, of course, many other facets to cavity preparation; however, this paper will be limited to the use of the material.

One of the complaints often made concerning amalgam restorations is the darkening of adjacent tooth structure. This can be minimized by coating the cavity walls with a varnish prior to filling. Such a liner prevents leakage during the first days after placement of the restoration as well as blocking the migration of metallic ions into the tooth tissues.

Alloy selection

Alloy selection and usage is based on the operator's technique and experience and the specific needs of the case. Excellent amalgam restorations can be placed with conventional lathe cut alloy, spherical alloy, or dispersion phase alloy. The alloy should of course appear on the ADA Certified List of dental amalgam alloys. The amalgam made from lathe cut alloy requires heavy forces on relatively small condensers to develop sufficient pressure for obtaining optimum properties, Figure 2.[8] A condenser point 0.1 inch in diameter requires approximately 8 pounds force to develop 1000 psi or 0.8 pounds to yield 100 psi. For lathe cut 1000 psi is required to develop adequate tensile strength while spherical alloy can be successfully compacted with 100 psi (0.8 pounds force). The forces required for the lathe cut are difficult to maintain throughout the day and in certain areas of the preparation. In many Class V and buccal extension type cavities it is difficult to apply matrices that can support these forces. Also, children don't understand the discomfort of heavy forces. Consequently, when using reduced forces there is a definite advantage in using spherical alloy.

The dispersion phase alloy[9] offers a different advantage in that the resultant amalgam is a two phase metallurgical system rather than the three phase amalgam made from the conventional silver, tin, copper, zinc or non-zinc alloy. The customary three phases in amalgam are: non-reacted alloy (γ phase), silver-mercury (γ_1 phase) and tin-mercury (γ_2 phase).

The γ_2 is not found in the amalgam made using the dispersion phase alloy, Dispersalloy.* This alloy has a silver copper eutectic (82% silver, 28% copper) in spherical shape dispersed within a conventional lathe cut alloy. Since the γ_2 (SnHg) is the weakest as well as the phase most susceptible to corrosion there is a distinct advantage to its being eliminated. Reports of clinical studies verify the laboratory prediction of increased resistance to corrosion and reduced flow at the margins.

Clinical evaluation and laboratory studies are in progress on a recently developed alloy in which 10% of the silver has been replaced with gold. Amalgam made using this alloy also has no γ_2 phase and consequently it, too, is corrosion-resistant. Whether this alloy will be produced commercially is dependent on results of several clinical trials now being conducted.

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* American Silver and Mercury Products, El Cajon, Calif.

Mixing the amalgam

The manufacturers of the various alloys have made extensive laboratory tests and clinical evaluations of amalgams made from their products. As a result of these studies the manufacturers have prescribed certain proportions of alloy to mercury, mechanical mixing equipment and trituration times. These procedures should be followed.

Basically, trituration accomplishes one goal; that is, to wet each alloy particle with mercury. Filings require more mercury and additional trituration time to cover each particle than do spherical alloys. Regardless of the reason, whether an oxide coating or the uneven surface, the filings must be triturated adequately to obtain optimum physical properties. More amalgams are probably defective due to under-trituration than to over-trituration. Laboratory and clinical studies have shown that the small shrinkage resulting from over-trituration does not contribute to failures,[10] as long as there isn't excessive over-trituration.

Since each mechanical mixing device has its own characteristics of speed, force and path of travel, it is recommended that trial mixes be made before an instrument is put into clinical use. Usually proportioning devices are accurate and will deliver mercury in consistent amounts. Pellets provide convenience with accuracy consequently it is easy to standardize to the manufacturer's directions. A prescribed capsule and pestle, if recommended, should be used in making several mixes at various trituration times. The correct mix should have mercury covering each particle. Add a second or two to the lowest trituration time that gives the proper mix. Pre-proportioned sealed capsules provide an easy opportunity to standardize the mix. With the proportioning devices now available the dental assistant, however, can provide equally consistent results. When pellets are used, a day's supply of capsules can be prepared in advance by supporting the pellets on top of the pestle to prevent contact with the mercury until triturated.

Condensation

Condensing the amalgam to a uniform mass is required for all of the alloy types whether the minimal or excess mercury technique is used. Lathe cut alloys require 1000 psi while 100 psi is needed for the compaction of spherical alloys. Using a number 2 Tarno condenser, approximately 0.1 inch in diameter, 8 pounds force is required to get the 1000 psi. The amalgam is compacted in small increments to prevent layering or void formation and with sufficient force and number of strokes to bring excess mercury to the surface.

As excess mercury is removed, the γ_1 and γ_2 matrix is reduced, leaving the amalgam mass more corrosion-resistant. This plashy amalgam is swept away for spherical as well as lathe cut alloys leaving a mercury-rich layer to receive the next increment.[11] As the cavity is filled and successively larger condensers are used extra force is required to deliver the necessary pressure. In order to develop at least 500 psi with the number 3 Tarno nearly 7 pounds of force must be used. The use of mechanical condensers, such as Hollenback and McShirley, provide an opportunity to substitute many relatively lighter strokes for the heavy manual condensation. However, ultrasonic condensation should not be used due to the potential mercury contamination from the shower of mercury-rich particles generated as this instrument is used.[12] It is essential to remember that time has passed rapidly during condensation and if three to four minutes have elapsed since trituration was completed, that mix should be discarded for it has lost its workability and its potential strength is reduced. If a fresh mix is not made the amalgam at the external surface, including the margins, will be of this over-aged material. This hardening amalgam will have an excess of residual mercury and a high number of voids due to reduced plasticity so its compressive strength will be markedly reduced. Thus, a fresh mix, thoroughly compacted and of maximum bulk for the final filling and overfilling of the cavity will contribute to less surface corrosion and decreased marginal deterioration. The mercury-rich amalgam in the excess is carved away with a sharp instrument. When the carving is completed the surface is smoothed by wiping with a wet cotton pellet. After the initial set, approximately 8 to 10 minutes following the trituration of the final mix, the surface is lightly burnished. This procedure, if done with light pressure and slow strokes, will further smooth the surface and reduce the porosity near the surface, Figure 3. If any heat over 140°F is generated, a mercury-rich, highly corrodible surface will be formed.

Any polishing procedures can be used that further smooth the surface but do not generate excessive heat. As the exposed areas are cut to a more smooth surface the total surface area will be reduced and composed principally of cut silver tin, γ phase, particles which are the strongest and least corrodible.

Plaque control

A smooth surface cavity forms as a sequelae of plaque retention. When the surface is repaired, plaque will again form and be retained on the replacement material. The presence of acid, oxygen and some anerobic areas on the metallic surface permits the anodic and cathodic reactions which are part of the corrosion process.[13] Therefore, the pitting observed at corrosion sites is accelerated by plaque accumulation. Additionally as the pitting increases, plaque is more difficult to remove and the secondary caries sequel to the original caries develops under the plaque covering the tooth adjacent to the new restoration. There may also be progression to periodontal involvement. Therefore, the dentist's responsibility of motivating the patient toward plaque control should continue even after restoration of the tooth.

Summary

Excellent long-lasting and esthetically acceptable dental amalgam restorations can be made using any alloy or mercury on the ADA List of Certified Materials. The principal cause of amalgam failure is corrosion with pitting or porosity and subsequent margin breakdown. Condensing the amalgam to reduce to a minimum the residual mercury content and porosity along with careful subsequent polishing will increase the percentage of corrosion-resistant phases on the surface. Additional factors contributing to failure such as fractured enamel rods at the margin, under trituration, amalgam fracture due to occlusal contacts, faulty compaction techniques and lack of plaque control by the patient are preventable by using the procedures discussed.

CEMENTS

How we treat dentin is directly reflected in the condition of the pulp. Dental caries and attrition gradually expose dentin tubules inciting the natural defense mechanisms of the tooth to form reparative and sclerotic dentin. This is contrasted with the operative procedures and trauma which immediately expose unaltered tubular contents to possible destructive forces such as heat, dehydration and chemicals. Generally, 2.0 mm of unaltered dentin between the floor of the cavity and pulp provides an adequate insulating barrier against irritating components of restorative materials.[14]

In cases of pulpal exposure a calcium hydroxide-containing cement, such as Dycal,* Hydrex,** Hydroxyline,*** etc., is more effective than any other class of cements in stimulating the formation of a dentin bridge over the exposure.[15] When there is danger of material such as zinc phosphate or silicate cements causing irritation of the cut tubules, protection can be obtained with copal varnish or a protective base of zinc oxide-eugenol, calcium hydroxide or polycarboxylate cement.

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* Dycal, L. D. Caulk Co., Milford, Delaware

** Hydrex, Kerr Manufacturing Co., Detroit, Michigan

*** Hydroxyline, George Taub Products, Jersey City, New Jersey

In addition to chemical irritation of the pulp, a chemical reaction of the base with the restorative materials must be avoided. Nearly every material which hardens by free radical polymerization should not contact eugenol-containing bases because the eugenol inhibits the polymerization. This is true for all acrylic resins, most composite filling materials and rubber base impression material.

Cements for this discussion will be limited to intermediary base and cementation materials. Cements for esthetic restorations will be covered later.

Intermediary base

The intermediary base materials are used to replace a portion of the lost dentin to prevent thermal and chemical irritation of the pulp tissue. They also may be used to modify the contour of the internal walls of cavity preparations. Since these materials line the pulpal and axial walls of the cavity, they require adequate strength to resist forces used in compacting amalgam and direct golds[16, 17] as well as the hydrostatic forces built up during cementation of precision-fit castings. The highest compressive stress is usually exerted during compaction of the dental amalgam or gold restoration and is within the first three to eight minutes after the cement is prepared.[18] Table 2 lists the early and ultimate compressive strengths of some of these materials. Adequate thickness of the intermediary base to disseminate the compressive forces is also important. It has been shown that 1 mm thick bases made of material exceeding 200 psi in strength will not crumble or be displaced by the usual condensing forces.[19]

Modifying internal cavity walls

Another function of a base material, modifying internal walls of cavity preparations, is required for indirect restorations, i.e., those completed outside the mouth to be cemented in place. Proper selection and use of materials for this function reduces the amount of tooth structure needing removal and thereby assists in retention of the restorations since parallelism can be achieved without removing excessive amounts of tooth structure. Selection of a material for this base need not be limited to the usual cements but can include dental amalgam and gold. The recently introduced adhesive polycarboxylate cement offers an additional choice, and will be discussed later.

Radiopacity

Since they are completely covered by permanent restorations, intermediary bases cannot be identified by visual examination. To facilitate subsequent interpretation of radiographs in the diagnosis of recurrent caries, the intermediary base should be radiopaque. The relative radiopacity of various materials is shown in Figure 4. Unfortunately, cements of calcium hydroxide and resins do not have this feature.

Mixing

The ingredients are carefully formulated and packaged by the manufacturer after exhaustive experimentation and testing. Carefully worded and illustrated instructions for each product are generally included in the package to insure obtaining optimum physical properties. Consequently, detailed mixing instructions will be omitted in this discussion.

Zinc phosphate cement

Zinc phosphate cement continues to be the standard used for the evaluation of physical properties for all new dental base and cementation materials. Table 2 shows the high early compressive strength and the severe pulpal inflammation resulting when this material is used on the floor of a cavity which is close to the pulp.

The powder for this cement contains approximately nine parts calcined zinc oxide to one part magnesium oxide and when mixed with the liquid containing phosphoric acid buffered with salts of aluminum or zinc, the compounds formed are phosphates of zinc, magnesium and aluminum. The liquid reacts with the surface of the particles to form a phosphate matrix that surrounds the core of unreacted powder. As the ratio of particle content to matrix increases better physical property values are obtained. This is true for all core matrix systems used in dentistry. Therefore, the operator should always try to obtain high powder-liquid ratios for these materials.

In the past few years a zinc phosphate cement has been introduced using water as the liquid which replaces the relatively unstable phosphoric acid. The resultant cements, when compared to the acid liquid zinc phosphate, have greater film thickness, less strength, higher solubility and are equally irritating to the pulp tissues.[20] Consequently, their use is contraindicated.

Zinc oxide eugenol cements

In the 1960's considerable research and development was focused on zinc oxide eugenol cements. The favorable response of the pulp to this material has always stimulated interest in improving physical properties such as compressive strength, solubility and film thickness.[21,22] Table 3 lists representative ZOE and modified ZOE products as they progressed from the addition of zinc acetate to hasten the set to the most recent additive, polycarbonate, which contributes strength and abrasion resistance. The products containing Al_2O_3 and poly-(methylmethacrylate) (PMMA) develop early compressive strengths that are in excess of the minimum 200 psi required to resist the forces used in compacting amalgam, Table 4. Virmani[17] reports that two modified ZOE cements, B & T* and Temrex Extra,** along with the zinc phosphate material Tenacin,* have sufficient early strength to resist forces necessary to place direct gold restorations.

Pulpal response to ZOE with additives (EBA, hydrogenated rosin, Al_2O_3 or PMMA) is similar to that of the unaltered ZOE.[23-24]

These cements are radiopaque, Figure 4, and can be used safely in deep cavities without endangering the pulp. When actual pulp exposures occur the formation of secondary dentin has not been as consistent with coverage by ZOE as with $Ca(OH)_2$. Therefore, when the operator senses he is close to the pulp tissue and there might be an undetected pulp exposure, use of these cements is not the treatment of choice. In these circumstances $Ca(OH)_2$ is indicated.[25-29]

Calcium hydroxide cements

Calcium hydroxide is an effective agent for the treatment of exposed pulp tissue. Unfortunately, it has very little,

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* B & T and Tenacin, L. D. Caulk Co., Milford, Delaware

** Temrex, Interstate Dental Company, New York, N. Y.

if any, strength and is moderately difficult to manipulate even when mixed with distilled water. There are several commerical cements containing $Ca(OH)_2$, e.g., Dycal and Hydrex which, when hardened, have sufficient early compressive strength to withstand compaction forces required for placing amalgam but not for direct gold, Table 2.[17] They also permit resolution of mild pulpal inflammation and stimulate the formation of reparative dentin. These materials are used mainly in deep cavities for their therapeutic effect on the pulp and for bases under resin restorations. When they are placed on dry dentin, they flow freely onto the dentin surface ensuring complete adaptation. Moisture accelerates hardening and interferes with coverage of the dentin wall. Calcium hydroxide is not radiopaque, therefore some of the commercial products have added varying amounts of radiopaque material, Figure 4.

Thanik[30] reported that with less than 0.1 mm of dentin, $Ca(OH)_2$ is the least irritating base material, with ZOE next and zinc phosphate cements the most irritating. To avoid pulp displacement and resulting injury in deep cavities, $Ca(OH)_2$ should be carefully placed over the dentin in the pulpal or axial walls because there may be an undetected pulp exposure. Sufficient bulk must be provided so the combined dentin and intermediary base will withstand compaction forces.

The $Ca(OH)_2$ bases are the material of choice under some composite and resin restorations so that there is usually no eugenol to interfere with polymerization hardening. Berk[28] demonstrated that these materials protect the pulp against irritation by silicate and zinc phosphate cements. They are equally effective in protecting the pulp under composite restorative materials.

Polycarboxylate cements

Polycarboxylate cements are a mixture of a modified zinc oxide powder and aqueous polyacrylic acid solution.[31] Duralon*, Poly-C**, Zopak[†], and PCA[‡] are among the representative products currently on the market. The results of several studies[31-33] show adhesion of Duralon to enamel and to a lesser extent to dentin. This adhesion to tooth structure is of interest in the potential use of the material as an intermediary base to modify the contour of tooth preparations. It can be painted on undercut areas and, upon hardening, the crown or inlay preparation can then be completed. Its early strength is not known. However, the 24 hour strength[33], Table 4, should be adequate to protect a thin dentin wall against displacement by hydrostatic forces that occur during cementation of castings. It is radiopaque, Figure 4, and

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* Duralon, Premier Products, Philadelphia, Penna.

** Poly-C, Claudius Ash, Inc., Niagara Falls, New York.

[†] Zopak, The Lorvic Corp. St. Louis, Missouri

[‡] PCA, S.S. White Mfg. Co, Philadelphia, Penna.

is less irritating to pulp tissue than zinc phosphate cement.[31,33] These properties indicate that this may be a useful material. The extremely critical method for handling polycarboxylates to obtain maximum adhesion is discussed later in the Cementation section.

Summary

The care with which the operator treats the dentin is directly reflected in the condition of the pulp. There are a wide range of materials available for use as intermediary bases, to aid dentists in maintaining health in the pulp tissues. The choice should be determined by the role the operator wants the material to fulfill, i.e., strength (zinc phosphate cement), non-irritation (ZOE, modified ZOE), dentin formation ($Ca(OH)_2$), adhesion (polycarboxylate), and radiopacity (all the zinc containing cements and others with radiopacity added). Frequently, a combination of materials is desirable such as calcium hydroxide to permit formation of a dentin bridge followed by either a ZOE or zinc phosphate cement. Some commercial preparations of $Ca(OH)_2$, such as Dycal and Hydrex, have sufficient strength to be used alone under dental amalgams. EBA or ZOE with alumina and hydrogenated rosin have improved the early strength so that these cements can be placed on freshly cut dentin with confidence that there will be no pulpal irritation and that the cement will withstand compaction forces. Studies concerning the response of the pulpal tissue to all the modified ZOE cements indicate that they retain the "kind-to-the-pulp" characteristics of unmodified ZOE. However, before new formulations and modifications of old ones are brought on the market, they should be evaluated for pulp tissue response. This is true for any product even though it may be only slightly varied in formulation from products that have been accepted clinically[34].

Cementation

Results of recent laboratory studies indicate that polycarboxylate cements may add adhesion to the list of factors responsible for retention of castings.

Included in the physical properties responsible for prolonged mechanical retention are: (1) high compressive strength; (2) good ability to wet the surfaces of the tooth and restoration; (3) high resistance to solubility and disintegration in the oral environment; and (4) low film thickness. Among many additional factors affecting retention are: (1) total area of the walls of the preparation; (2) degree of parallelism of opposing walls; (3) accuracy of fit of the restoration; and (4) direction of forces of occlusion in relation to the path of insertion of the restoration or appliance.

The criteria for selecting a cementing medium are based on the need for these physical properties and the biological response of the pulp tissue to the cement. The ease of handling also has a bearing on selection since this is extremely important for the clinician.

Jørgensen[35] presented a comprehensive analysis of various operator-controlled factors which affect film thickness. He states that the more viscous the cement the more difficult it is to seat the restoration completely. Viscosity may be dependent on inherent characteristics of the cement, powder-liquid ratio, duration of mixing time and temperature. Once the cement is mixed and placed on the materials to be cemented, the viscosity will have been established, and will increase with time as the setting reaction proceeds. The amount and method of applying the positioning forces then becomes the principal factor controlling residual film thickness at the tooth-restoration interface. The operator should apply a steady force[35] of approximately 10 pounds until the cement has hardened. A small dab of wet cement on the adjacent tooth provides a good test sample. An additional element contributing to low film thickness is venting of the casting. In this way the hydraulic pressure is released as the cement escapes. An accurately fitting casting seated with a minimum of film thickness takes full advantage of the frictional resistance, compressive strength and adhesion.

Film thickness is a part of the American Dental Association Specification No. 8 for dental zinc phosphate cement.[4] Two types of cement based on powder particle size are specified as Type I or II. Maximum film thickness permitted for Type I is 25 µm (0.001 inch). Type II may have a film thickness up to 40 µm (0.0016 inch). Type I is designed to permit seating of precision castings. Type II is suitable for all other uses. The manufacturer should specify on the package the type of cement. Manufacturers should state in their directions the appropriate powder-liquid ratio required to obtain the specified film thickness. The physical properties are also used as a standard for comparison of the other classes of cementing materials as listed in Table 4.

Zinc phosphate cement

Zinc phosphate cement, Type I, (Tenacin, Fleck's* and S. S. White Zinc Improved**) continues to be the standard for comparison of retention of new materials being developed for luting precision castings. Although zinc phosphate is irritating to the pulp tissue, varnish (two thin layers) or a base of either $Ca(OH)_2$ or ZOE covering unaltered dentin effectively protects the pulp. A thin layer of varnish does not reduce

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* Fleck's, Mizzy, Inc., Clifton Forge, Virginia

** S. S. White Mfg. Co., Philadelphia, Penna.

the retentive strength of the zinc phosphate cement.[36]

Eugenol as an additive to the liquid is not ------------ effective in reducing pulpal irritation. If the sedative effect of zinc oxide-eugenol is desired, temporary cementation with a ZOE cement is recommended. Permanent cementation with zinc phosphate cement can be delayed until pulpal health has returned.

Water settable zinc phosphate cements are inferior to the conventional zinc phosphate and should not be used, Table 4.[20,37]

Polycarboxylate cement

The polycarboxylate cements, such as Duralon, Poly-C, Zopak and PCA, were first introduced for cementation of stainless steel to enamel.[31] Smith claims that the carboxyl bonds are available immediately after mixing and that they form a bond with the calcium ions in the tooth. Etching or other pretreatment of the enamel surface so far has not changed the bond strength.[38] Thermal cycling apparently has no effect on strength. Water uptake[32] and solubility are quite high in laboratory testing and indicates that long-term clinical testing is required before routine use can be recommended.

Strict observance of the mixing instructions is necessary to obtain the maximum properties of the polycarboxylate cements.[31]

The powder-liquid proportion for cementation should be between 1-1/2 to 2-1/2 parts of powder to one part liquid by weight, depending on the manufacturer's instructions. The desired consistency should be developed through trial and error. Once the proportions are determined mixing can be completed by bringing all the powder into the liquid and spatulating quickly. Unfortunately, present methods of powder and liquid dispensing are inadequate to allow this technique to be followed with accurate results. The mixing should be completed in less than 30 seconds and the mix placed on the restoration and tooth immediately. Correct powder to liquid ratio and usage well before the gloss disappears from the mix will develop the strongest adhesive and the most desirable physical properties[31]. Operators who have used this cement are enthusiastic over the lack of discomfort experienced by the patient during and subsequent to cementation.

Although polycarboylate cements were specifically formulated for cementation of stainless steel orthodontic appliances to enamel, tests have been made on retention of gold cast crowns with teeth prepared with a 10° taper[39]. Results have also been reported on laboratory tests of gold castings in Class I cavities prepared in recently extracted teeth[33]. A comparable force was required in both experiments to remove crowns cemented with zinc phosphate and polycarboxylate cements. ZOE with polymer had about one half the retentive strength of polycarboxylates. These laboratory tests do not indicate a superiority over zinc phosphate cement for cementing gold crowns.

Modified zinc oxide-eugenol and EBA cements

The modified zinc oxide-eugenol and EBA cements discussed in the intermediary base section are sometimes used as luting agents for castings. Some have certain physical properties as indicated in Table 4[21,40] which are comparable to zinc phosphate cement. Viscosity and wetting ability are superior to zinc phosphate cement.

In light of the favorable qualitites, these cements are growing in popularity as luting agents. The EBA cements with Al_2O_3 have compressive strength and retention values similar to zinc phosphate cement, Table 4, but are higher in their solubility values[21]. Solubility and disintegration data based on the ADA Specification No. 8 test yield lower values for EBA cements[4]. Another aspect of disintegration related to solubility but not determined by the 24 hour residue is the loss of eugenol as shown by Wilson and Batchelor[41] These investigators claim that aqueous leaching of eugenol from the ZOE cement (unmodified) is continuous as the cement matrix hydrolyzes to eugenol and zinc hydroxide. Thus, the cement in 20 weeks time lost mechanical strength and disintegrated. This long-term process is not evident in the 24 hour specification test.

As with the zinc phosphate, mixing for intermediary base and cementation differ only in the proportion of powder added to a given amount of liquid.

Well controlled, long-term clinical studies of cementation with modified ZOE or EBA have not been reported. Two progress reports[42,43] have indicated favorable results over a short period of time. However, other operators are observing failures after one year, especially in those cases involving bridge abutments or short crown teeth. Consequently, until long-term (three years or more) well controlled studies are reported, these modified ZOE cements are not recommended for general use in permanent cementation of restorations.

Silico phosphate cement

Silico phosphate cements, such as Kryptex,* Lucent,** and Fluorothin* may be termed hybrid cements for the powder is a mechanical mixture of about nine parts silicate and one part zinc phosphate cement.[44] Since the liquid is similar to that used for the zinc phosphate cements the same handling precautions are necessary.

The compressive strength of these products is superior to zinc phosphate while solubility is inferior,[45,46] Table 4.

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* Kryptex and Fluorothin, S. S. White Mfg. Co., Philadelphia, Penna.

** Lucent, L. D. Caulk Co., Milford, Delaware

Fluoride (a basic ingredient of the silicate portion) is gradually leached out and may increase the resistance of the adjacent enamel to caries.[47] In addition, the retention of crowns and castings is almost as great as that obtained with zinc phosphate cement.[36] The manipulative characteristics, viscosity and film thickness, however, make it difficult to seat closely fitting castings. Several brands have recently been introduced which meet the film thickness specification of 25 μm for Type I zinc phosphate cement.

This type of cement, because of its silicate-like translucency, is used principally for its esthetic value in cementing materials such as porcelain and resins.

Acrylic resin cements

The physical properties, esthetic qualities and manipulative characteristics of acrylic cements are similar to the direct filling acrylic resins. Solubility, which is near zero, and surface wettability, are two properties which are superior to zinc phosphate cement. This surface wettability, or adaptation, makes it seem as though a bonding reaction has occurred. The apparent bonding is lost, however, as the cement absorbs water and the cement-tooth interface becomes wet.[48] They should not be used.

Recently, a cementing medium has been introduced which is based on the resin present in most of the composite resin materials. This cement, Epoxylite Crown and Bridge Adhesive,* though it is insoluble, has excessive film thickness for precision casting and is dependent upon an etched surface for mechanical retention. Until this material can be prepared with sufficiently thin film thickness to completely seat precision castings or its clinical behavior has been assessed in long term studies it cannot be recommended for general use.

Polyurethane

In recent years polyurethanes have attracted much attention as potential adhesive liners and tissue sealants. These materials are still in the experimental stage but appear promising.

Summary

For many years cementation of precision-fit castings has been dependent on a material which combines resistance to breakage with mechanical or frictional locking of the casting to the tooth. With the introduction of polycarboxylate cements adhesion to enamel surfaces may be obtained. This material, with its apparent adhesion countering the

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* Lee Pharmaceutical, South El Monte, Calif.

lower compressive strength, resists removal of castings similar to zinc phosphate and silico phosphate cements.

Careful handling of all the materials is essential. Optimum physical properties result when the maximum percentage of powder is mixed within the range of the manufacturer's instructions. To get the maximum retention, the cement must be applied to the tooth and the restoration as soon as possible after the mix is completed.

ESTHETIC RESTORATIVE MATERIALS

The materials available for use as direct filling esthetic restorations range from the silicate cements and the unfilled resins to the more recent composite resins. Each will be discussed along with clinical techniques.

Silicate cement

The silicate cements have one overriding desirable property. The continuous leaching of fluoride from the silicate acts to decrease the susceptibility of the adjacent enamel to caries. Other desirable attributes are the low setting shrinkage and the close similarity of its coefficient of thermal expansion to that of dental hard tissues. Undesirable characteristics include the severe inflammation in pulps not protected during placement of the silicate and its high solubility in most mouths. Silicate restorations, however, sometimes will last for many years if placed: (1) in a tooth isolated by a rubber dam; (2) using the correct powder-liquid ratio; and (3) protected with a silicone grease or wax for the first six hours after placing. The low pH associated with plaque is primarily responsible for the disintegration of silicate restorations. Even so, many operators continue to favor silicates for individuals with a high caries incidence because of the caries resistance brought about by the presence of the fluoride. Other than for this purpose, its usage is probably not recommended.

Unfilled resins

Unfilled resins such as Bonfil* and Sevriton Simplified** have had a bad reputation that is principally due to misuse of earlier similar products through lack of sufficient knowledge and techniques. Adequate esthetic restorations can be placed by using techniques which compensate for the principal weakness of the unfilled resin, i.e., shrinkage during curing. Other weaknesses include a coefficient of thermal expansion at great variance from dental hard tissues and a low resist-

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* Bonfil, L. D. Caulk Co., Milford, Delaware

** Sevriton Simplified, Claudius Ash, Inc., Niagara Falls, N.Y.

ance to abrasion. Etching the enamel[49] at the resin-tooth interface and using the Nealon Bead, or brush, technique to place the resin enhanced the marginal seal and the retention of the restoration. These improvements result from each increment wetting and covering completely the tooth surface or previous portion of resin. In this way, each addition tends to fill the space formed by the curing shrinkage of each prior portion. With this technique these materials can be used to restore Class V cavities, fractures of incisal angles when less than one half the mesial distal tooth width is involved, and defective areas such as hypoplastic pits on the labial surface of anterior teeth. Retention is enhanced when pins are used as a supplement to the etching technique.

These direct filling resins have a low resistance to abrasion and lack color stability in the mouth. Restorations showing wear and color change can be renovated by removing some of the labial or esthetic surface and then brushing on new material.

Some manufacturers have added fluoride to their resin to imitate the anticariogenic effect of the fluoride in silicates. The lack of favorable results from this additive may be because the resin is insoluble and the fluoride is not gradually leached out as in silicates.

Composites

Composite resins are replacing the silicate cements and the unfilled resins for direct filling, esthetic restorations in non-load-bearing areas. These resins have a matrix material based in general on a formula developed by Bowen.[50] The resin matrix and silane treated fillers (glass beads, glass rods, quartz, lithium aluminum silicate, silica, fused silica, or borosilicates) form unique composite materials in that the particles are chemically bonded to the resin matrix, Figure 6. Some of the fillers contain glasses that are radiopaque. The treated filler makes up about 70-80% by weight of the composite material. As a result the coefficient of thermal expansion and susceptibility to abrasion are greatly reduced as compared to the unfilled resins. Data on various composite materials, silicate and unfilled resins, are given in Table 5. The physical properties of composites are superior to the unfilled resins in the following: abrasion resistance, curing shrinkage, coefficient of thermal expansion, modulus of elasticity and compressive strength. The toughness and the low solubility of the composites give them a decided advantage over silicate cements. The low curing shrinkage of the composites enables the operator to bulk pack these materials. One of the greatest disadvantages of the composites (and silicates) is the difficulty in obtaining a good final polish.

The biological response in the pulp tissue to composites is similar to that for silicate cements. A pulp protecting base of calcium hydroxide is used since the eugenol in zinc oxide-eugenol materials usually interferes with the polymerization of the resin matrix.

The setting reaction on the surface of composites is somewhat inhibited by air. Therefore, care should be taken to ensure that the materials are covered by a grease or matrix strip during set.

One of the difficulties encountered during placement is the presence of voids at the tooth-composite interface. The use of an injection tube technique may reduce these voids by making it possible to flow the material onto the base of the cavity and filling from the inside out.

One of the brands, Blendant*, has been made radiopaque. This is an advantage in radiographic diagnosis.

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* Blendant, Kerr Mfg. Co., Detroit, Michigan

Polishing the composites to a high lustre is currently impossible. The extreme contrast in hardness between the matrix and filler and the presence of innumerable voids prevent polishing with available techniques. It is hoped that a successful technique can be developed. One suggestion by Chandler[51] is the use of diamond particles in the size range of 1 to 5 μm on a flexible disk or strip.

The best surface finish is that which cures next to the matrix strip. However, some cutting for contour and margin perfection is always necessary. This can be done with a 12-bladed carbide bur using ultra speeds to lightly brush the excess away, being careful not to injure the adjacent tooth structure. Following this shaping with the bur successively finer lubricated cuttlefish disks and strips will develop the best finish currently available, Figure 6.

Several manufacturers claim that composites can successfully replace amalgam in load-bearing areas of posterior teeth. The only long-term clinical study to be reported[52] (three years) indicated a significant loss of anatomical contour. A current study[53] is in its second year and the results of these observations are required before routine use in posterior teeth can be recommended. Figure 8 shows the loss of a composite material after 18 months as observed in our program at the National Bureau of Standards.

Future developments will probably include a coupling agent for bonding the restorative material to enamel. This would give true adhesion to the enamel. Until such a system is perfected further refinement will probably be made in cavity surface pretreatment such as etching. Additional improvements are needed in color matching, color stability and polishing to make the composite materials more permanent and esthetic.

Summary

Composite resins are becoming increasingly popular as direct filling esthetic restorations. They are designed for use on non-load-bearing areas such as the interproximals of anterior teeth and gingival areas of all teeth. As the polishing procedure is improved, these materials will probably replace silicate cements.

Enamel pretreatment by etching is effective in improving the marginal seal and retention of unfilled resins. This type of restoration is for slight, less than one half tooth width, enamel fracture on anterior teeth.

FISSURE SEALANTS

Fissure sealant materials are primarily intended to seal or fill anatomical defects. There are essentially two types of material, one is inert and can be regarded as being in the restorative material category. The other, containing a fluoride additive, is considered a carrier for an active ingredient having a potential therapeutic effect. Only the inert material will be discussed here.

Considerable clinical evaluation should be completed before accepting pit and fissure sealants for general use. Clinical studies concerning an inert resin have been reported[54] and appear promising. The formulations of one sealant resin, Nuva Seal,* is similar to that proposed by Bowen[50] for use as the matrix material in the composite resins. An ultra-violet activator replaces the chemical activation usually used, and there is no filler. Another sealant, Epoxylite Fissure Sealer 905** (which is chemically activated) has been more recently introduced and has the same potential effectiveness as Nuva Seal but here, too, reports of long-term studies are needed. The claim for adhesion by these materials to enamel is questionable since both depend on acid etch pretreatment for retention. However, this mechanical retention by penetration of the material into the etched surface is reported to be effective in retaining the material for at least six months.

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* Nuva Seal, L. D. Caulk Co., Milford, Delaware

** Lee Pharmaceutical, South El Monte, Calif.

The lack of adhesion is a cause for some concern. The rapid progression of decay under a loose orthodontic band or a gold inlay raises the question as to what will happen if a sealant loosens but is retained because it is wedged in place. Another question concerns the progress of existing but undiscovered caries in a pit when a sealant is applied. It is most difficult to diagnose this type of caries early in its progress even by an experienced examiner. This could be a problem if the treatment is being applied by a relatively inexperienced individual on a mass treatment scale.

Fissure sealants are being subjected to extensive clinical study. If the current promising results hold up over long periods of observation, they may become an excellent adjunct in the preventive caries program.

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Table 1

REASONS FOR PLACING RESTORATIONS

New caries			
Smooth surface	199		
Anatomical defect	106		
		305	
Replacements			
Cavity preparation (self cleansing, undermined enamel)	52		
Material (handling, selection) silicate, amalgam, resin	67		
		119	28%
TOTAL		424	

Table 2

Intermediary Base

	Material	Compressive Strength				Pulp Response **
		Early 7 min		Ultimate 24 hr		
		MN/m^2	psi	MN/m^2	psi	
Zinc phosphate	Acid	7.5	1100 (16)*	108	16900 (16)	++++ (30)
	Water settable	not available		66.1	9550 (20)	++++ (20)
Zinc oxide-eugenol	Zinc acetate	3.9	600 (16)	8.6	1250 (16)	++ (25,29, 30)
	EBA & Al_2O_3	39.3	6000 (10 min) (21)	88.4	13000 (one week) (21)	++ (23,24)
	PMMA	5.8	900 (16)	13.7	2000 (16)	++ (23)
	Cavetec	2.9	400 (16)	5.2	750 (16)	++ (16)
Calcium hydroxide	H_2O	0	0	0	0	- (25,29, 30)
	Dycal	7.5	1100 (16)	7.5	1100 (16)	- (16)
	Hydrex	3.4	500 (16)	9.8	1400 (16)	- (26)
Polycarboxylate		not available		34.4	5000 (33)	++ (33)

* Figures in parentheses represent reference

** Pulp response

a. Exposure

Dentin bridge	-

b. Dentin unbroken

Mild inflammation	++
Moderate inflammation	+++
Severe inflammation	++++

Table 3

ZINC OXIDE-EUGENOL CEMENTS

Composition		Commercial Products
Powder	Liquid	
ZnO Hydrogenated rosin Zn acetate	Eug	Intermediary bases Temporary restorations Periodontal packs Root canal sealers
ZnO Hydrogenated rosin	EBA Eug.	Opotow EBA ProCem Ultim EBA EBAC Temrex Extra
ZnO Al_2O_3 Hydrogenated rosin	Eug. EBA	Opotow EBA with alumina ProCem with alumina
ZnO PMMA	Eug. Acetic acid	Fynal IRM B & T Opotow temporary
ZnO Polystyrene	Eug.+ ?	Kalzinol
ZnO Polycarbonate	Eug.+ ?	Decigenol
ZnO Polymerized resin Carnaba wax Zn acetate	Eug. Mineral oil	Cavitec (ingredients blended in two tubes)

Table 4

PHYSICAL PROPERTIES OF VARIOUS MATERIALS MIXED TO CEMENTING CONSISTENCY

Material	Time of Setting	Compressive strength 24 hr		Film thickness	Solubility and Disintegration (by wgt)	Diametral tensile strength 24 hr		Relative retention ZP = 100
	min	MN/m^2	psi	µm	%	MN/m^2	psi	
ADA Spec. #8 Type I (cementing) (4)	5 min. 9 max.	68.6	9956	25 maximum	0.2 maximum	No specification		No specification
Zinc phosphate acid	5.5	103 (22)	15000	18 (36)	0.2 (22)	80	12300 (16)	100 (36)
water settable	8.5	61 (37)	9000	75 (20)	0.4 (20)	not available		not available
ZOE + EBA and alumina(Al_2O_3)	9.5 (22)	93.6 (22)	14000	26 (22)	0.05 (22)	4.8	700 (40)	100 (36)
ZOE + polymer (PMMA)	6-10 (40)	48.1 (40)	7000	32 (16)	0.08 (40)	6.8 (40)	1000	55 (36)
Silicophosphate	$3\frac{1}{2}$-4 (45)	274*	29500* (45)	42 (46)	0.4 (45)	Not available		80 (36)
Resin cement	4-10 (48)	65.7** (48)	9500 **	10-60 (48)	0.0-0.4 (48)	Not available		Not available
Polycarboxylate	7.5 (33)	31.4 (33)	4600	21 (33)	0.6 (32)	5.4 (32	800	100 (33)

* 7 days
** 1 hour

Table 5

PHYSICAL PROPERTIES

		Compressive Strength	Coefficient of thermal expansion	Shrinkage on cure
		psi	ppm/°C	%
Tooth	Enamel	14-56,000	8-11	
	Dentin	30,50,000	4-8	
Silicate		24-31,000	8	0.03-0.25
Unfilled resin		14,000	80	2-3
Composite		27-40,000	22-35	0.22-0.6

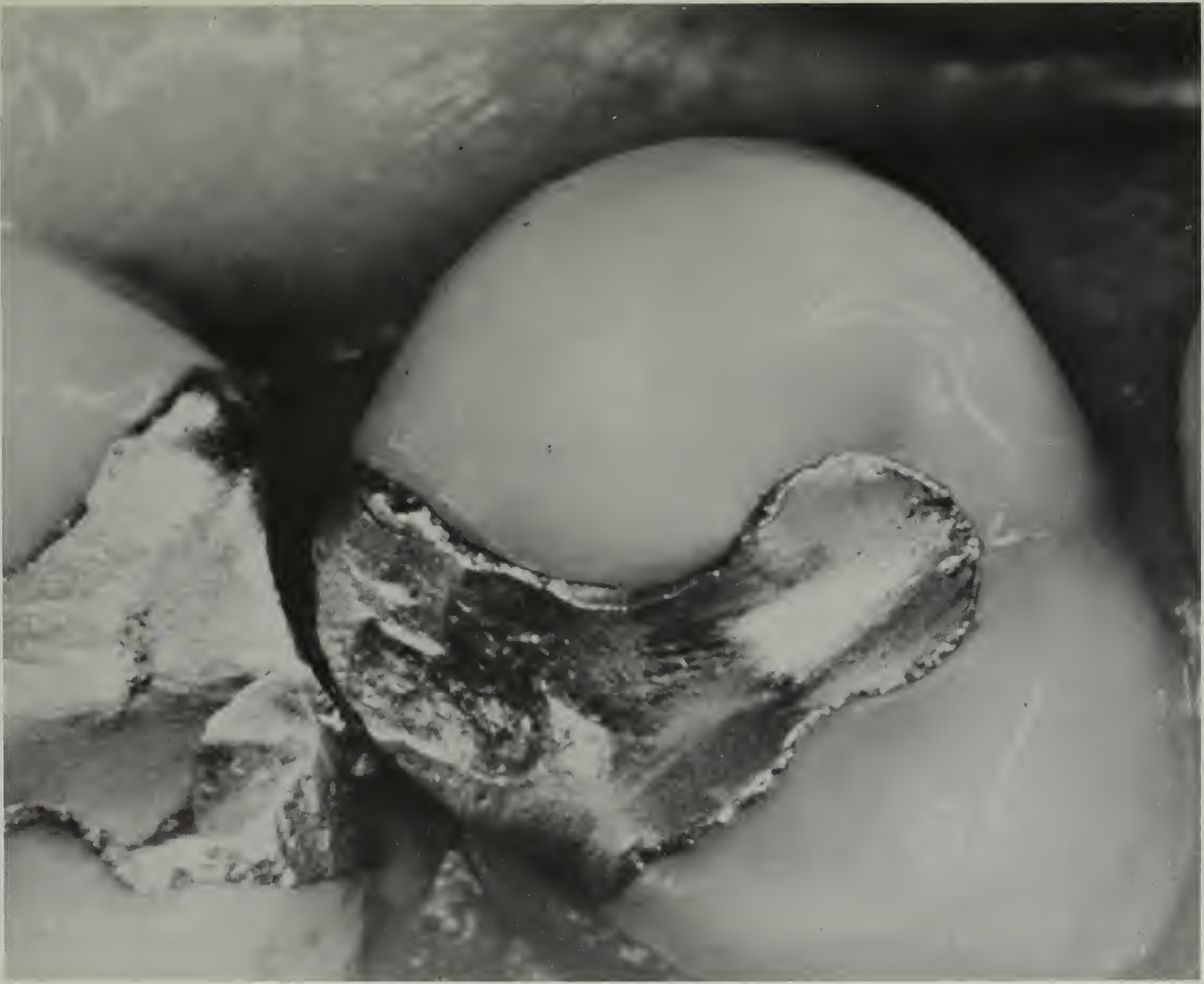

Fig. 1. Amalgam fillings in place as least one year.
(Wann, W. L., J. Am. Dent. Assoc. 73:1321, Dec. 1966).

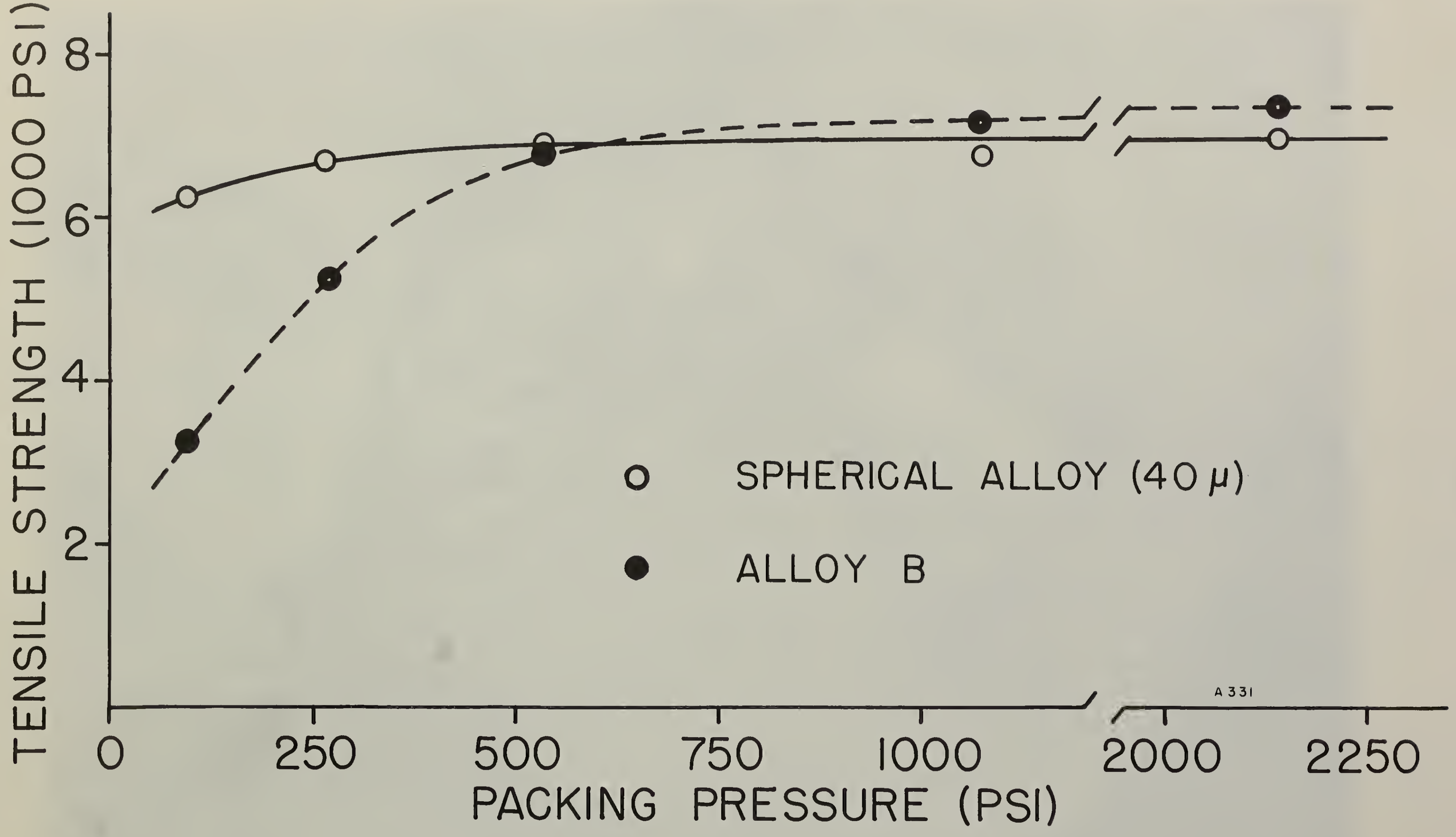

Fig. 2. Packing pressure vs. tensile strength.
(Average particle size given for the spherical alloy)

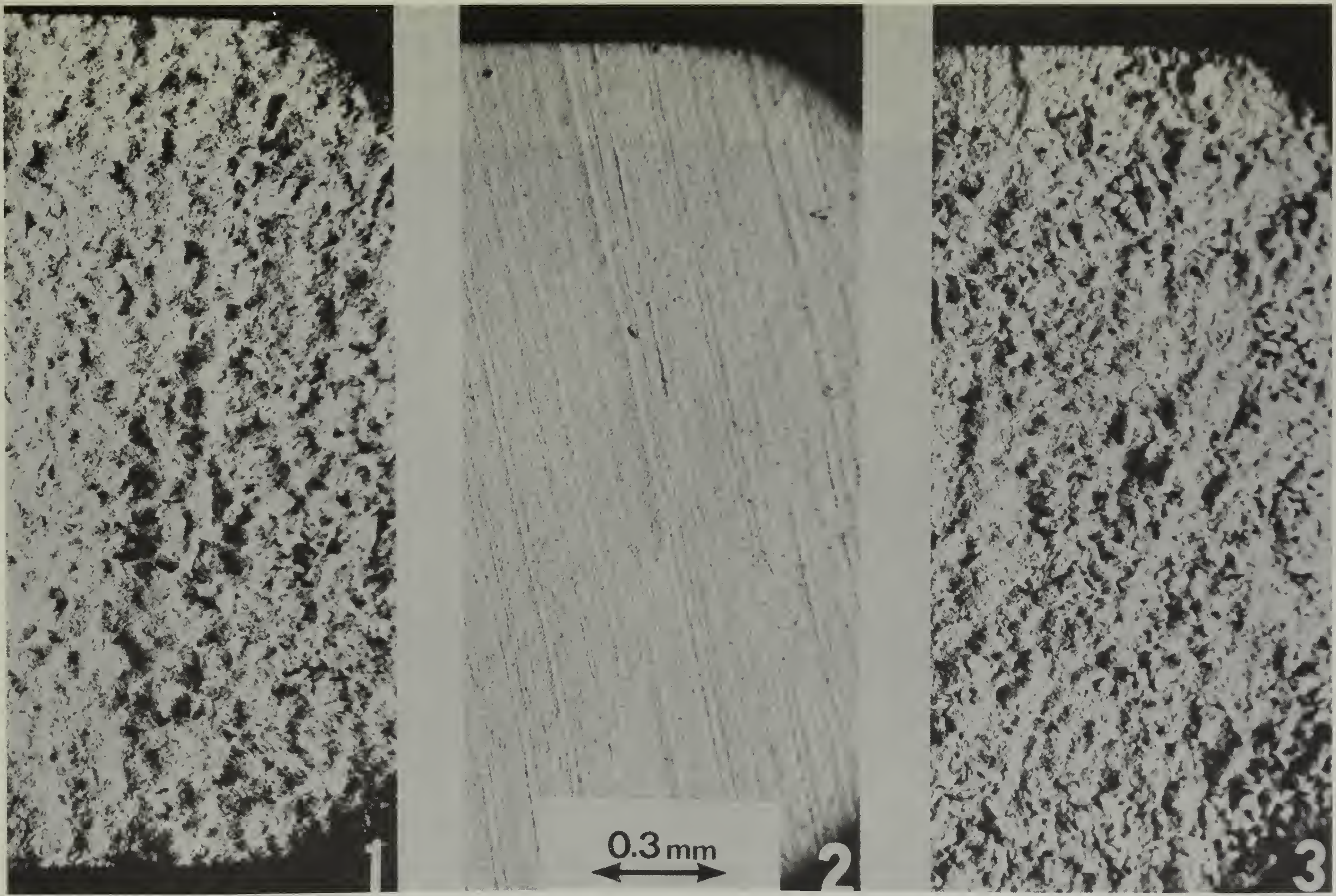

Fig. 3. Scanning electron microscope pictures of amalgam surface after various finishings at first appointment. 1) carved with a sharp instrument; 2) carved with a sharp instrument then at 11 minutes after start of last mix the surface was lightly burnished; 3) carved with a sharp instrument and wiped with a wet cotton pellet.

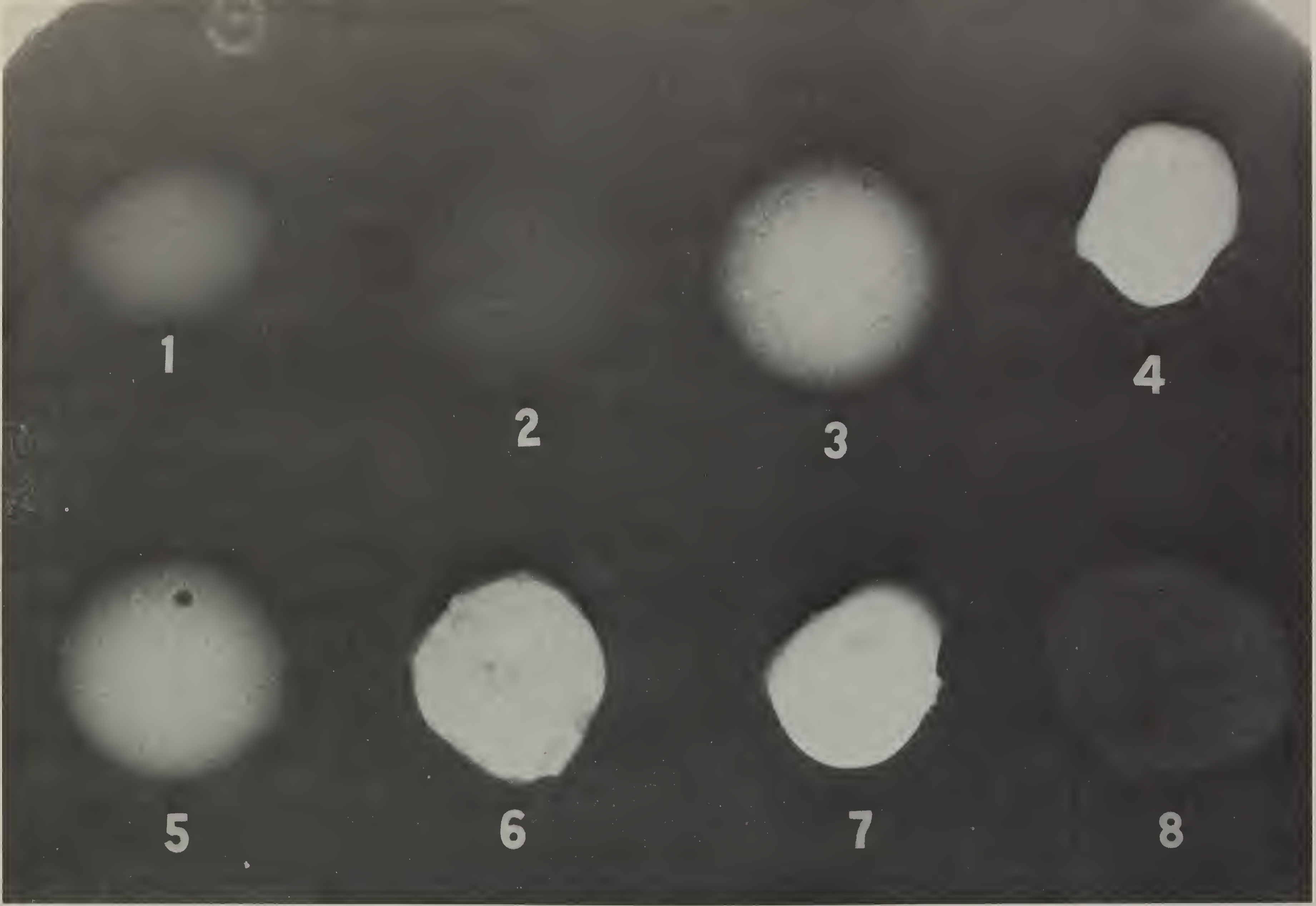

Fig. 4. Radiograph of various materials of similar thickness. 1) CaOH-Dycal; 2) CaOH-Hydrex; 3) ZOE-Cavetec; 4) $ZnPO_4$, Fleck's; 5) ZOE-EBA-Al_2O_3-Opotow; 6) ZOE-PMMA: B & T; 7) Polycarboxylate, Durelon; 8) Composite-Adaptic.

Figure 5

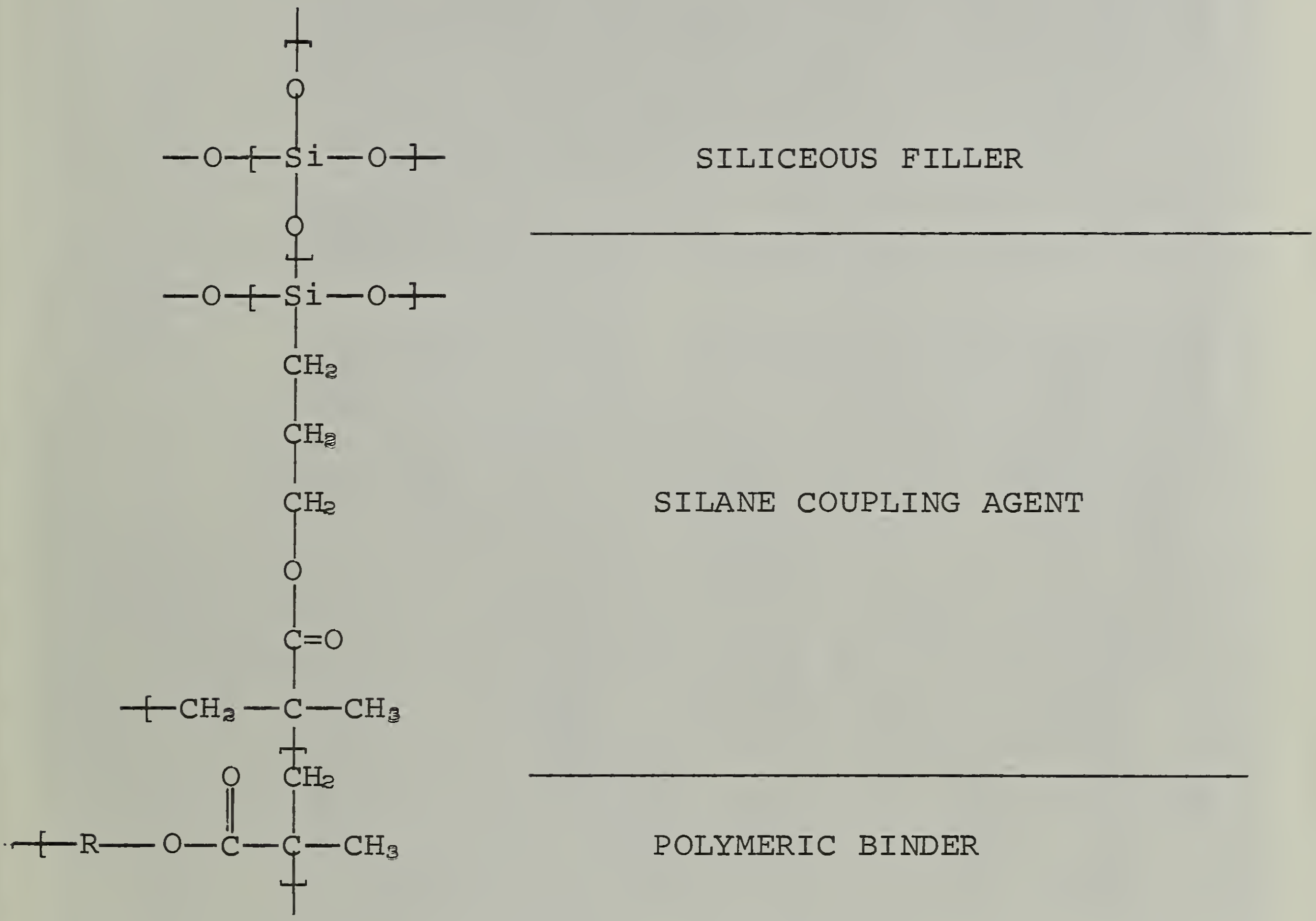

Fig. 5. Simplified schematic diagram of the means of bonding between resin and filler.

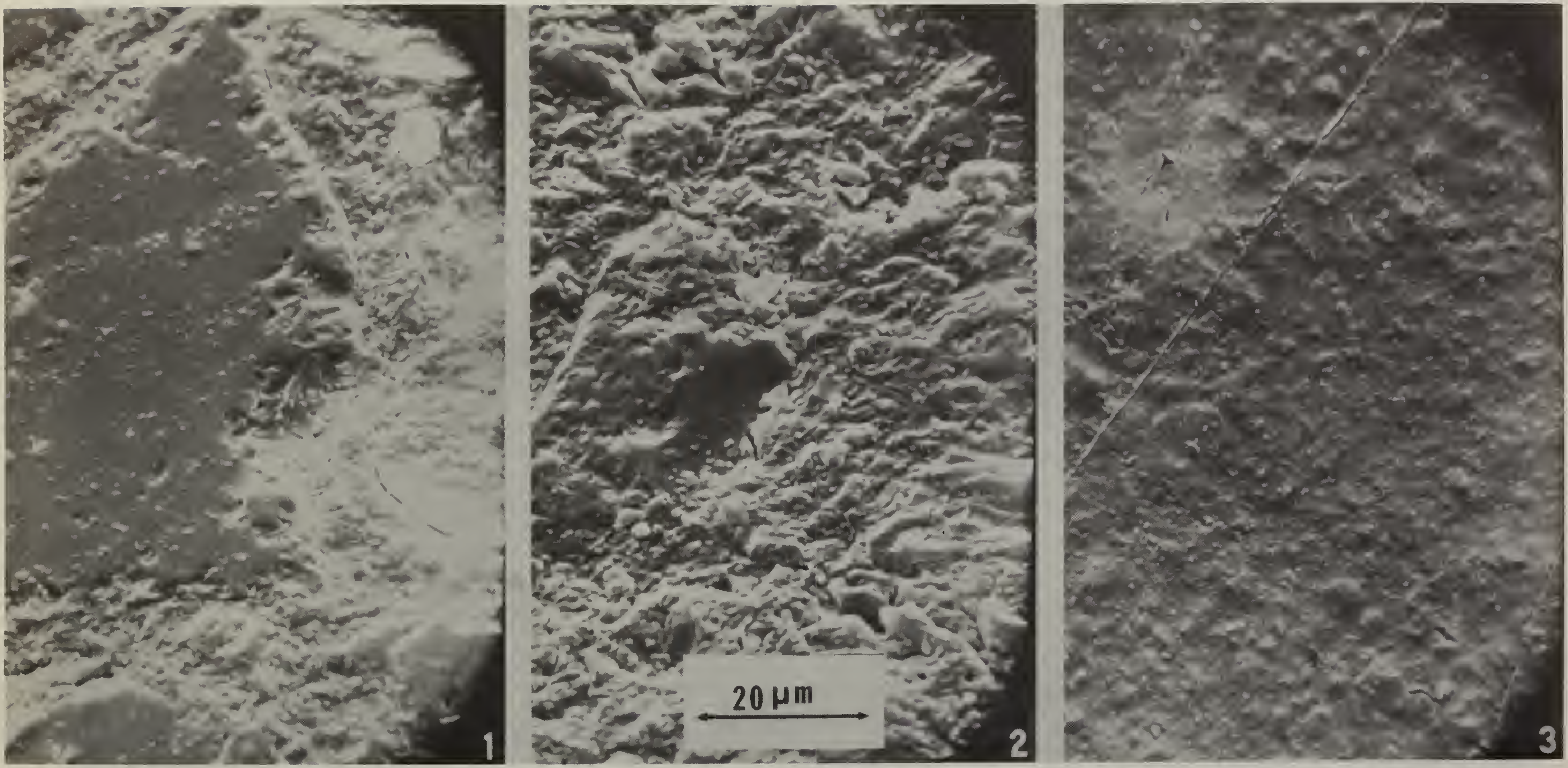

Fig. 6. Scanning electron microscope pictures of the surface of composite resin following two finishing procedures. 1) Diamond particles (1 to 5 μm) on paper disk; 2) Successively finer cuttlefish disks with cocoa butter lubricant; 3) As set against glass surface.

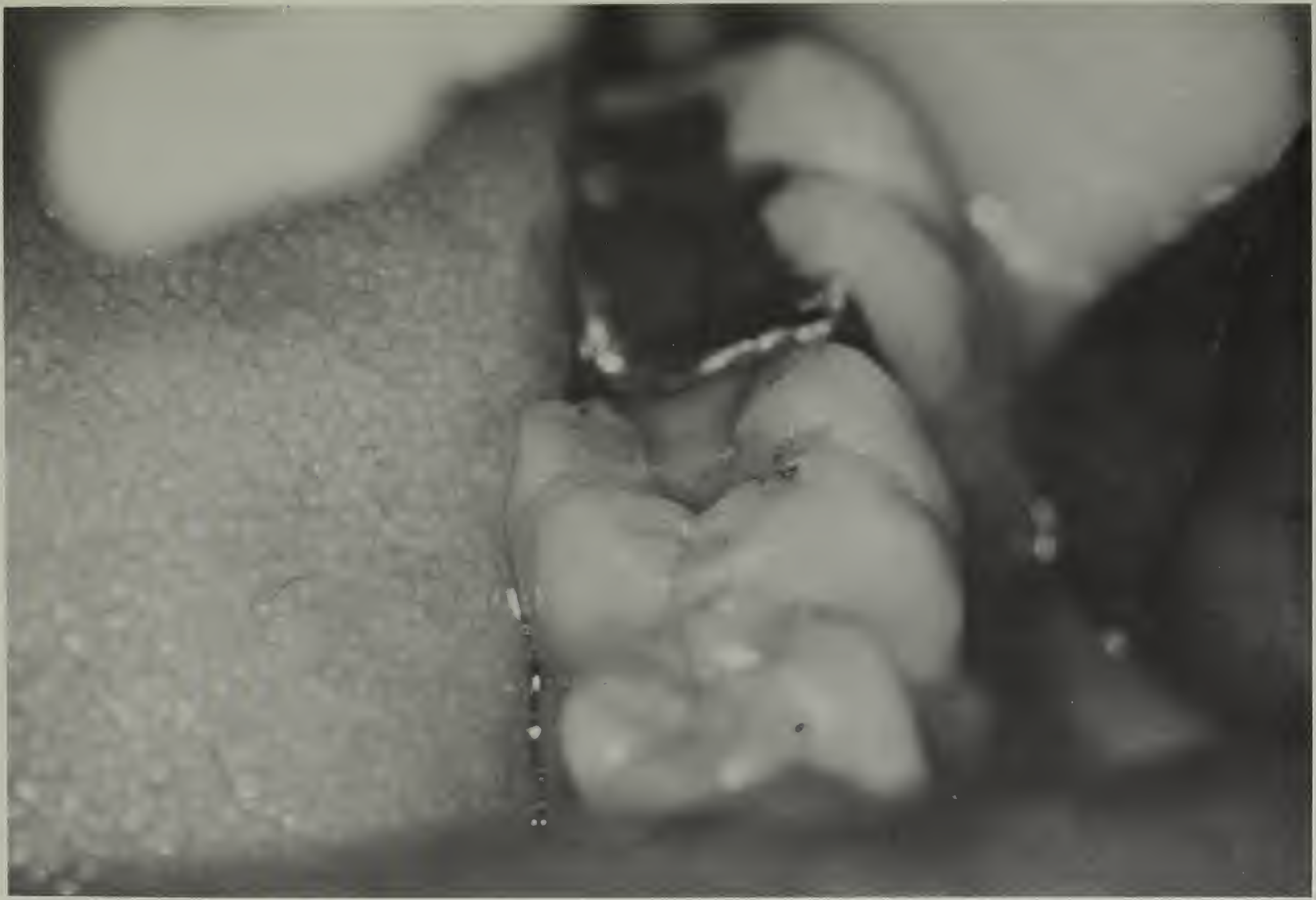

Fig. 7. Class II (DO in functional first molar) in place 18 months. Approximating amalgam placed and marginal ridge carved to the composite contour six months prior to this picture. Note loss of composite material in the 12th to 18th month.


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