OPERATIVE DENTISTRY

ACADEMY OF AMERICAN GOLD FOIL OPERATORS

ACADEMY OF OPERATIVE DENTISTRY

spring 1987 • volume 12 • number 2 • 41-88

(ISSN 0361-7734)

OPERATIVE DENTISTRY

SPRING 1987 • VOLUME 12 • NUMBER 2 • 41–88

Aim and Scope

Operative Dentistry publishes articles that advance the practice of operative dentistry. The scope of the journal includes conservation and restoration of teeth; the scientific foundation of operative dental therapy; dental materials; dental education; and the social, political, and economic aspects of dental practice. Review papers and letters also are published.

Publisher

Operative Dentistry is published four times a year: Winter, Spring, Summer, and Autumn, by:

Operative Dentistry, Inc
University of Washington
School of Dentistry SM-57
Seattle, WA 98195 USA

POSTMASTER: Send address changes to this address. *Operative Dentistry* is the official journal of the American Academy of Gold Foil Operators and the Academy of Operative Dentistry.

Subscriptions

Yearly subscription in USA and Canada, $35.00; other countries, $45.00 (sent air mail); dental students, $22.00 in USA and Canada; other countries, $31.00; single copy in USA and Canada, $12.00; other countries, $15.00. Make remittances payable (in US dollars only) to *Operative Dentistry* and send to the above address.

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E D I T O R I A L

Posterior Composites: For Routine Use in Today's Practice?

It seems as though dentistry is always embroiled in some form of controversy. Sometimes these differences have been significant and have divided the profession, as did the "Amalgam War" over a hundred years ago. In recent years we have seen a resurgence of the "mercury toxicity" issue, in which some dentists remove silver amalgam restorations on the premise that they are detrimental to the patient's health.

Today's major controversy arises from the increased use of composite resins in posterior teeth. The real issue is: Are composite resins suitable as a posterior restorative, particularly as a replacement for silver amalgam?

At one extreme are those dentists who no longer use proven metallic restorations in the posterior segment and have turned almost entirely to the use of posterior composites; at the other extreme, there are those who continually denigrate the users of composite resins in any form, let alone for posterior teeth. Dr Robert Sheldon Stein, assistant dean for clinical affairs, Boston University, summed up the conservative view at the recent annual meeting of the Academy of Operative Dentistry when he asserted, in his review of restorative procedures, that too much "white stuff" is being placed. Many dentists fit somewhere in between the extremes and are unsure of which way to turn. Let us look, for a moment, at what the dentist is confronted with.

Many patients are demanding esthetic restorations. At no time in the past has esthetics been of such high priority as it is today. Some of this demand can be attributed to the manufacturers of composite resins, who advertise in lay magazines, encouraging readers to seek out such care as the use of posterior composites, the "bonding technique," and esthetic veneering.

Manufacturers have been touting the use of composite resins for posterior teeth for a number of years. We can look back at the numbers of resins which have come and gone because they did not hold up in the oral environment, and yet, as each new brand is introduced we are provided only laboratory data as a basis for the superiority of any new product. Of course, most products are on the market for several years before any clinical data become available. Many of the products have been altered or withdrawn before the first results are published.

Dr Paul Lambrechts, in delivering the Buonocore Memorial Lecture at the Academy's February meeting, cautions dentists to be slow in adopting the use of posterior composites as a routine substitute for dental amalgam, particularly in the more posterior areas of the mouth, as stress levels are higher there. He notes that little clinical evidence supports the longevity of composite resin in the oral environment.

It is reasonable to assume that products that are continually being removed from the market or altered in their chemistry or filler particle composition, size, and so forth will always be difficult to assess. As Dr Lambrechts points out, we must recognize that laboratory values for strength, wear, color stability, and other physical property values generated in the laboratory do not equate with clinical success, no matter how convincing the sales approach may be.

There are many clinical problems associated with the use of posterior composites. They are time consuming, costly, laborious to place, and good contacts and contours are difficult to achieve, even for the best of operators. Postoperative sensitivity continues as a problem, at least for some; not all dentists admit to a problem.

Dr Nelson "Woody" Rupp at the National Bureau of Standards tells me that he continually hears of vitality problems and pain associated with the use of posterior composites. Practicing endodontists tell him they don't need the extra business being generated by the placement of posterior composites and that when patients have pain and a single posterior composite resin has been placed, they look at the tooth with the composite first — from past experience they find it high on the list.

Having checked with three endodontists in the past few days, my suggestion is that you also do the same. It might be enlightening to you.

Another point to consider: Are most of the problems being generated by a small group of incompetent dentists doing shoddy work?

From all the evidence available today, it seems as though caution should be our watchword. Or are we going to let the manufacturers get by with the promotion of products which as yet remain unproven for the long haul? Seems to me that if the dentists continue to buy, then the manufacturers are going to keep on hawking their wares.

Remember the watchword — it is CAUTION!

DAVID J BALES

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ORIGINAL ARTICLES

Effects of Preparation Design on the Resistance for Extensive Amalgam Restorations

P J J M PLASMANS • S T KUSTERS • A M G THISSEN
M A VAN 'T HOF • M M A VRIJHOEF

Summary

In an investigation in vitro, the influence of various preparation designs for extensive amalgam restorations on the resistance level and failure characteristics of restored human molars was investigated. An oblique force was applied on four different designs. The results indicate that the number of steps used in the preparation design is important to increase resistance. No significant difference in resistance level was found whether cusps were partially eliminated and protected with amalgam or completely eliminated and supplied with auxiliary pinhole retention. All recorded resistance levels were above the maximum recorded bite force in the human dentition.

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Introduction

When preparing teeth for partial veneer crowns, onlays, or amalgam restorations, protection of unsupported or weakened cusps is of ultimate importance (Shillingburg, Jacobi & Brackett, 1985). Previously reported data suggest that weakened cusps may be unable to resist occlusal forces (Blaser & others, 1983; Bagheri & Chan, 1984; Cavel, Kelsey & Blankenau, 1985). Braly and Maxwell (1981) stated that cusps restored with amalgam are not suited to provide a long-term, stable occlusion.

The introduction of auxiliary methods of retention and the improvement of dental amalgam alloys have made it possible to produce larger and more durable amalgam restorations (Letzel, 1984). The use of auxiliary retention in severely damaged teeth has shifted the emphasis from creating adequate retention to that of providing adequate resistance to prevent further loss of tooth structure through fracture. Retention is defined as preventing removal of the restoration along the path of insertion or long axis of the teeth. Resistance prevents dislodgment of the restoration by, for example, biting and chewing forces directed in an apical or oblique direction (Shillingburg, Hobo & Whitsett, 1976).

Historically, investigations evaluating the retention and resistance characteristics of extensive amalgam restorations have been performed in vitro (Outhwaite, Garman & Pashley, 1979; Davis & others, 1983; Seng & others, 1980; Plasmans & others, 1987). Usually, flat dentine surfaces were prepared and the type of retention and resistance created was evaluated by means of applying external loads to the restoration. However, in clinical situations, flat one-surface cavity designs occur infrequently. It is often possible to create steps or varying levels within a preparation, increasing retention and resistance to occlusal forces.

When fabricating large amalgam restorations it is important to reduce weak cusps and reconstruct them with amalgam (Birtcil, 1981; Goerig & Mueninghoff, 1983). Little information is available about the failure characteristics of amalgam restorations onlaid with amalgam in relation to the level of covering and enclosure of cusps (Salis & others, 1985).

The purpose of this study was to investigate under laboratory conditions the influence of four preparation designs on the failure characteristics of the restored teeth when an external load was applied.

Materials and Methods

Twenty-four freshly extracted and matured sound human permanent molars, stored in 100% humidity, were used. The root portion of the teeth were embedded individually with cold-curing acrylic resin in a cylinder to a level 2 mm apical to the cementoenamel junction. Occlusal surfaces were reduced perpendicular to the long axis of the cylinder with a conventional model trimmer using water so as to provide a flat tooth surface 4 mm above the cementoenamel junction.

The 24 molars were assigned, at random, to six experimental groups, each consisting of four molars.

Figure 1 illustrates the occlusal and sagittal view through the preparations, there being six groups of specimens. For experimental specimens I & II and III & IV, the design of the cavity was identical for each pair but the application of the load was different. Experimental specimens V and VI were symmetrical, therefore used only in a singular group.

The four preparation designs were:

I & II. The buccal half of the molar was reduced to 2 mm above the cementoenamel junction, forming a vertical 2 mm step with the lingual half. At the buccal side, auxiliary retention was provided by means of two amalgam pinholes, made at the line angles of the buccal half 0.75 mm from the dentinoenamel junction and 2 mm deep by means of a #1157 round-

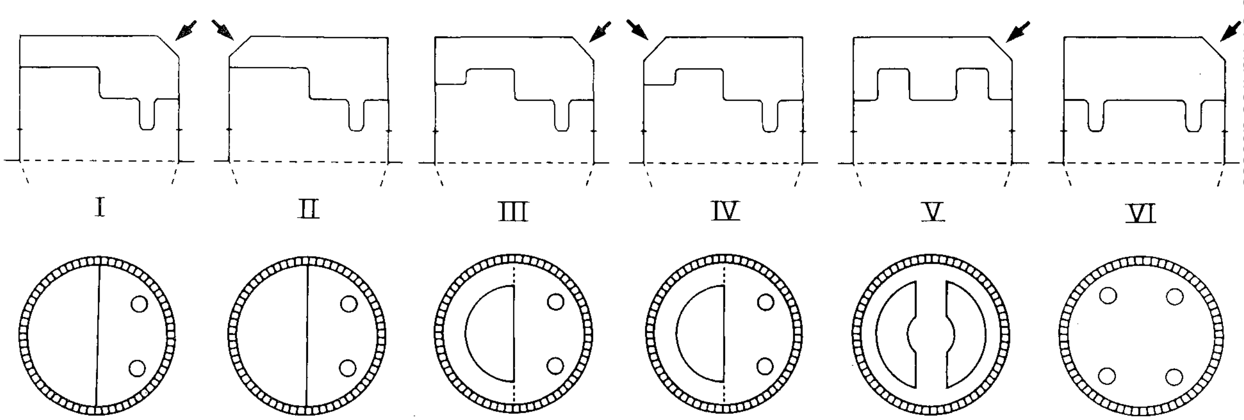

FIG 1. *Schematic occlusal and sagittal view of the preparation designs and the loading direction (I-VI)*

nosed bur (S S White, Philadelphia, PA 19102) (Shavell, 1980). The pinhole margin was beveled with a round bur (Fig 1, I & II).

III & IV. Starting with the same basic design as preparation I & II, the lingual side was additionally prepared with a horizontal step 2 mm wide and 1 mm deep (Fig 1, III & IV).

V. For design V, both the buccal and lingual side were provided with a circumferential horizontal step 1.5 mm wide and 2 mm deep and an occlusal groove 2 mm deep was prepared mesiodistally through the occlusal surface. The groove was widened until 2 mm of dentine both lingual and buccal were left (Fig 1, V).

VI. For design VI, the occlusal surface was further reduced to create a flat cavity 2 mm above the cementoenamel junction. Four amalgam pinholes 2 mm deep were added in the line angles of the tooth surface (Fig 1, VI).

For fabricating the amalgam restorations, a Tofflemire (Produits Dentaires, Vevey, Switzerland) matrix was used. Pieces of matrix material, wooden wedges, and impression compound were used to close the gap between the matrix-retainer flanges. Cavex non-γ-2 amalgam (Cavex Holland, Haarlem, The Netherlands) was condensed with a mechanical vibrator (Bergendal, Kavo, Biberach, FR Germany).

The matrix was not removed for at least 30 minutes after final condensation. The specimens were aged at ambient temperature for one week. The amalgam restorations were trimmed perpendicular to the long axis of the cylinder to a length of 6 mm above the cementoenamel junction so as to provide an effective restoration height of 4 mm. A diamond stone was used to remove overhanging margins of the amalgam and to prepare a bucco-occlusal or linguo-occlusal bevel in the amalgam, necessary for applying the force to the specimens. The bevel was prepared at an angle of 45° to the long axis. All specimens were prepared by one operator.

Design VI was regarded as a control to facilitate comparison of the results with a similar previous investigation (Plasmans & others, 1987).

A rounded metal bar (3 mm wide) was used to apply the oblique force at the buccal or lingual side of the specimens. All test specimens were placed in a mounting jig and loaded in a mechanical testing device (Instron Corp, Canton, Mass 02021) at a crosshead speed of 0.5 mm per minute. Crosshead displacement and load were recorded continuously. The resistance level was defined as the point at which a specimen could no longer withstand increasing load. The first dip in the load-crosshead displacement curve was taken as the point of failure. After this first dip, the load was increased until visible failure occurred. All specimens were classified as restorable or unrestorable. Fractures extending more than 2 mm below the cementoenamel junction were classified as unrestorable.

Results

The results of the six experimental groups are shown in Figure 2. For each specimen, both the force required to cause failure and the type of fracture are given. The influence of the preparation design on the resistance level was investigated by means of an analysis of variance. Tukey's multiple range test ($\alpha = 0.05$) was used to find mutual differences between the experimental groups (see table).

Mean Resistance Level and Standard Deviation in Newton for the Experimental Groups in Ascending Order

Experimental Group	$\bar{x}$	SD	Subgroup
II	698	133	1
IV	1007	203	1, 2
VI	1205	87	2
III	1347	235	2, 3
I	1402	234	2, 3
V	1553	299	3

The vertical lines depict homogeneous subgroups without significant difference between the corresponding experimental groups (Tukey's multiple range test, $\alpha = 0.05$).

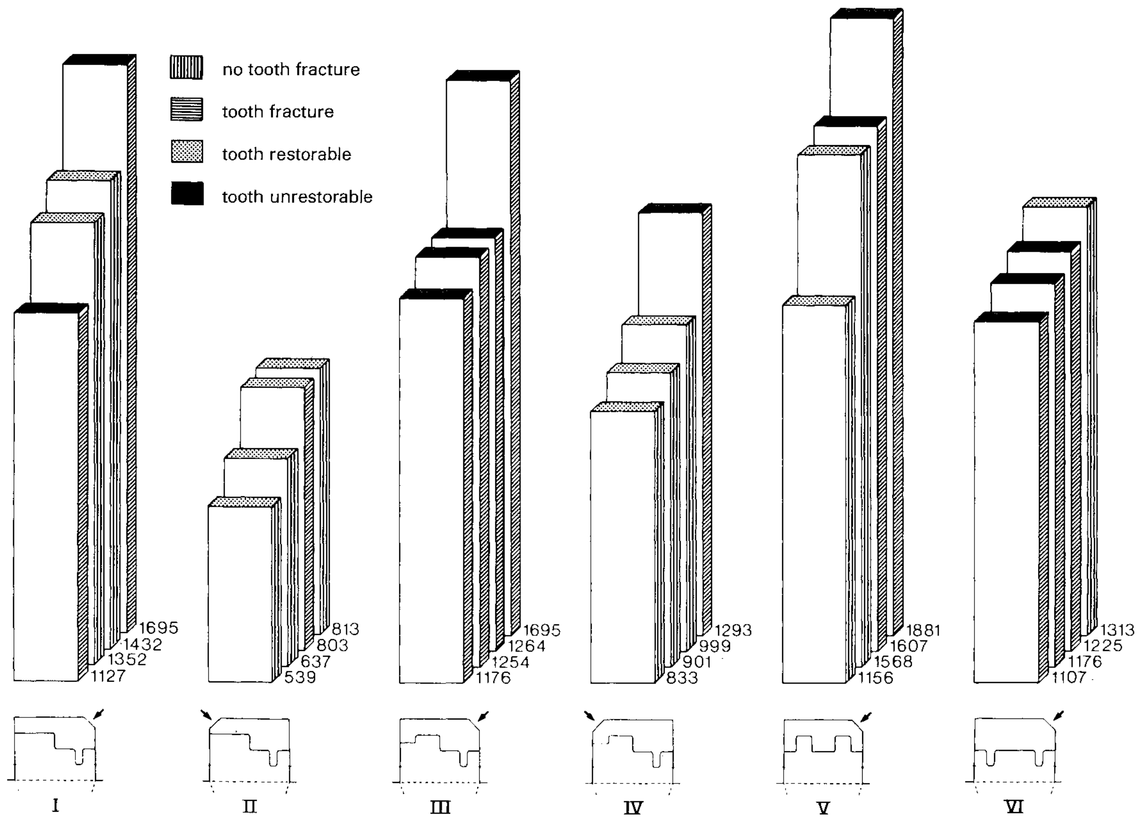

FIG 2. *Distribution of the resistance levels over the six experimental groups. For each specimen the preparation design, the direction of applied force, the recorded failure resistance (in newton), and the failure characteristics are given.*

The results show that Experimental Group II has the lowest mean resistance level while Group V showed the highest value. The three subgroups were detected using the multiple range test (II, IV; IV, VI, III, I; VI, III, I, V), indicating that no significant difference could be found in them at a level of α = 0.05. Experimental Groups II and IV (subgroup 1) have a significant lower resistance level than Groups VI, III, I, and V (subgroup 3).

To understand the effect of the investigated resistance features in a preparation design, knowledge of the direction of the force is important. If the force is directed away from the step there is no effect to be expected. A step is regarded as effective when the force is directed toward it. Only amalgam pinholes provide effective resistance to oblique forces from all directions.

All experimental groups consisted of two effective step methods with the exception of Experiment II, with one effective step method (two pinholes). When Experimental Groups II and IV (subgroup 1) are compared with regard to effective resistance features, it can be stated that the 1 mm step in Experimental Group IV has no significant influence on increasing the mean resistance level. Specimens of Experimental Groups IV, VI, III, and I (subgroup 2) all have two effective resistance features. Combinations of a pair of pinholes plus a 1 mm step (Group IV), two pairs of pinholes (Group VI), and a pair of pinholes plus a 2 mm step (Groups III and I) introduce no significant differences among the four experimental groups of subgroup 2.

The specimens of Experimental Groups VI, III, I, and V (subgroup 3) also all have two effective resistance features. From the lack of significant differences in this subgroup it can be concluded that the effect of a pair of pinholes compared to the effect of a 2 mm step shows no significant difference.

The influence of the 1 mm step in Experimental Group IV is not consistent. Compared with Group II, no influence could be detected. Compared with Groups VI, II, and I the influence equals the effect of a pair of pinholes or a 2 mm step. The effect must be considered as intermediate between no resistance and as much resistance as a 2 mm step or a pair of pinholes.

For six specimens, no failure characteristics could be detected at the recorded point of failure. However, after the final breakdown all specimens showed tooth fracture. Only one of these specimens could be classified as restorable (see Fig 2).

Discussion

The resistance levels found in Experiment VI (control experiment) are in accordance with the results of earlier research on the resistance of extensive amalgam restorations using amalgam pins (Plasmans & others, 1987).

With regard to the failure characteristics and the capability to restore the tooth following failure, no clear conclusion can be drawn. Only the tooth specimens of Experimental Group II were considered restorable after failure whereas in all other experimental groups one or more specimens were classified as not restorable. This can be explained by the fact that in Experimental Group II the resistance provided by the tooth structure is less than in the other experimental groups. Thus, if only fracture of amalgam occurred, the tooth can be classified as restorable.

It has been long assumed that a large amalgam restoration weakens the tooth. However, Re and Norling (1981) found that under an axial load more force was required to fracture molars with large restorations than molars with smaller restorations. Sound natural mandibular molars required a mean axial force of about 3000 N to fracture. It has to be realized that application of an axial force measures the strength of amalgam rather than the retention and resistance. Salis and others (1985) found that for premolars under an increasing impact force, MOD amalgam onlays were the equivalent of intact teeth, where the fracture resistance of conventional MOD amalgams was significantly reduced. However, the effect of repeated and increasing impact forces on a specimen is unpredictable and therefore not suited to measure the resistance level of extensive amalgam restorations to forces. For this reason an oblique force which resembles the clinical situation more closely was applied in this research (Outhwaite & others, 1979). The reciprocating dynamic forces during functioning in the mouth are not the same as the static force used in these tests. However, it is almost impossible to duplicate these forces in vitro.

It is to be expected that designs with more remaining tooth structure have a higher failure resistance than the design with only amalgam pinholes (VI). However, no significant difference could be found between the experiments I, III, V, and VI. This implies that when oblique force is applied it does not make any difference whether a cusp is onlaid with amalgam or is totally eliminated with auxiliary retention created with amalgam pins as an integral part of the restoration.

Conclusion

In this study almost all specimens could resist an oblique load force of more than 800 N. That is more than the highest reported forces occurring in the mouth (Helkimo & Ingervall, 1978). The results in vitro thus indicate that extensive amalgam restorations may function adequately under clinical conditions. Cusp protection is considered essential in such designs with at least 2 mm of amalgam on the cusps to provide the necessary strength. Clinical research needs to be conducted to study these preparation designs when subjected to actual dynamic masticatory forces.

It may be concluded from this in vitro research that:

- The failure resistance of an amalgam restoration is influenced by the extent of the step used in the preparation design.
- Two steps provide more resistance than one step.
- The resistance provided by a 2 mm step equals the resistance provided by two amalgam pins.

• The results obtained would justify clinical research in a study of the resistance behavior of extensive amalgam restorations under clinical conditions.

Acknowledgment

This research is part of the research program "Restorations and Restoration Materials." The authors would like to thank Frans Lourens for his valuable technical assistance.

(Received 27 December 1985)

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Solubility of Cavity Varnish: A Study In Vitro

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Summary

Cavity varnish has been shown to be an acceptable material to reduce marginal leakage and tooth sensitivity when used with silver amalgam restorations. However, concern has been expressed that cavity varnish may be soluble and lead to latent increased marginal leakage when used with high copper content alloys. This study reports the results of tests in vitro on the solubility of cavity varnish.

INTRODUCTION

Cavity varnish is widely used under silver amalgam restorations. The main functions of cavity varnish are to reduce marginal leakage between the restoration and the cavity walls, reduce tooth sensitivity after the restoration is placed, and help reduce the penetration of deleterious constituents of restorative materials into the dentin (Swartz & Phillips, 1961; Barber, Lyell & Massler, 1964; Phillips, 1976; Yates, Murray & Hembree, 1980). Phillips (1976) stated: "Varnish prevents the early marginal leakage that occurs around every amalgam restoration until corrosion products form around the interface." Research has also shown that cavity varnish reduces the adverse histological responses observed in the pulp of teeth following cavity preparation and restoration (Edwards, 1978) and that cavity varnish reduces, in vitro, the occurrence of secondary caries-like lesions under amalgam restorations (Grieve, 1973).

Recent studies indicate the newer high-copper alloys are slower in the formation of corrosion products and take longer to seal the margins as compared to the traditional alloys (Andrews & Hembree, 1980; Fayyad & Ball, 1984). Studies have shown that the permeability of cavity varnish increases with time and that at the end of six months there is no significant difference between varnished and unvarnished walls in the uptake of certain ions from silicate cement (Tveit & Hals, 1978; Younis, 1977). Furthermore, it has been reported that marginal leakage exhibited by amalgam restorations with high-copper content increased with time in cavity preparations that had been sealed with varnish (Smith, Wilson & Combe, 1978; Sneed, Hembree & Welsh, 1984). They have suggested that this increase in marginal

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leakage might be due to the loss or dissolution of cavity varnish in the testing solutions.

This study was undertaken to investigate the solubility of cavity varnish commonly used under silver amalgam restorations. Because there was no reported method for determining solubility of cavity varnish either by the American Dental Association or in the literature, it was necessary to develop a method or methods with which to conduct our experiments. The study was divided into two parts, utilizing two different methods to investigate the solubility of cavity varnish.

METHODS AND MATERIALS

Part I

Three cavity varnishes were selected for this portion of the study because they had been used in previous studies of marginal leakage and to represent both the copal and noncopal varnishes available: copal resin varnish, Copalite (H T Bosworth Co, Skokie, IL 60076) and noncopal resin varnishes, Cavi-Line (L D Caulk Co, Milford, DE 19963) and Universal (S S White Co, Philadelphia, PA 19102).

Two test solutions were used for evaluating the solubility of the varnishes in vitro, namely, normal saline and Ringer's solution. The test solution baths consisted of 300 ml of test solution placed in a closed, lidded, glass laboratory jar and were changed with each experiment, as well as the jars being carefully cleaned to prevent cross-contamination of solutions or experiments.

Twelve experimental specimens were prepared by applying varnish to glass cover slips. The clean specimens were selected, dried, and weighed. Three layers of varnish were applied, air dried for one hour, placed in a drying oven for one hour, placed in a dessicator for one hour, reweighed, and the weight recorded as the initial experimental weight for each specimen. The specimens were placed in carrying trays with individual receptacles allowing the test solution to surround each specimen. They were then put into the test solution, the lid placed on the glass laboratory jar, and left for seven days at room temperature. The pH of the test solution was measured and recorded at the beginning and end of each experiment.

After the prescribed time period, the specimens were removed from the test solution, air dried for one hour, placed in the drying oven for one hour, returned to the desiccator for one hour, reweighed, and the weight recorded, providing a final experimental weight. The weight loss was determined by subtracting the final experimental weight from the initial experimental weight for each specimen. Means and standard deviations were calculated for each set of 12 experimental specimens and the degree of solubility determined for each varnish test solution and time period. Control specimens without varnish were handled in a manner similar to that of the experimental specimens to verify the accuracy of the procedures and the weighing methods employed. All weighing was done on a Mettler Analytical Balance (Mettler Instrument Corp, Heightstown, NJ 08520) capable of weighing to 0.1 milligrams.

Part II

A cavity varnish, Universal (S S White Co) was labeled with radioactive isotope 14-C. This was accomplished with the help of the manufacturer who provided us the varnish formula and assisted with the labeling. Radioactive cellulose ([14C(U)] 5-20 Ci/mg) was purchased from New England Nuclear (549 Albany St, Boston, MA 02118) to substitute for the cellulose in the varnish formula. Satisfactory labeling of additional brands of cavity varnish/liners was not found to be possible.

Two test solutions were used as described in the first part of this study.

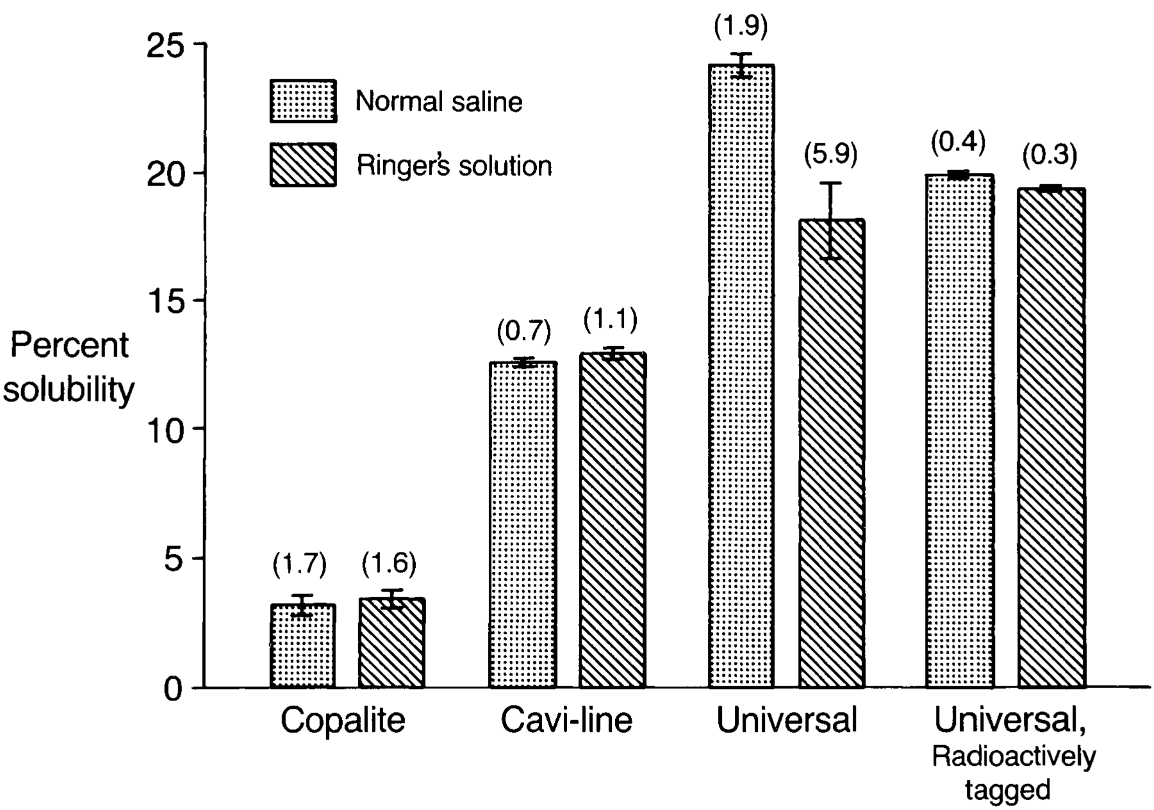
Ten specimens were prepared to be used as standards. Fifty microliters of the radioactively labeled varnish were applied to a 3/4" x 1" frosted glass slide surface and allowed to dry. Each specimen was then placed in an individual counting vial, the counting fluid (15 cc's of scintillation fluid, 2 cc's of water plus 1 cc of ethyl acetate) added, and the initial disintegrations per minute (d/min) were measured and recorded for each specimen and vial. These initial d/min provided the standard count against which the other counts were compared and experimental results determined.

Ten experimental specimens were also prepared and used for each testing solution. Fifty microliters of radioactively labeled varnish were applied to the surface of each specimen and allowed to dry. The specimens were placed in carrying trays with individual receptacles so they did not touch, put in the prescribed testing solution, and into the lidded laboratory jar. The specimens were retrieved at the end of seven days, placed in individual counting vials, and the counting fluid added as with the standard specimen. The final d/min were counted and recorded for each specimen and vial. Five control specimens were prepared using Universal cavity varnish without the radioactive label but were processed in the same manner as the standard and experimental test specimens. These were used to provide the background d/min (count) in our calculations.

Following the seven-day immersion of the specimens in the test solution, three 1 ml aliquots were taken from the test solution, placed in counting vials, 20 cc's of Aquasol (New England Nuclear) added, and the d/min measured and recorded for each aliquot. These were used to determine the amount of labeled cavity varnish in the solution, help determine the solubility of the cavity varnish, and account for all of the radioactive material. Means and standard deviations were calculated for each set of standard, experimental, and control specimens. The degree of solubility of the labeled varnish was determined using initial counts, final counts, and aliquot counts. Less than 5% of the radioactivity was unaccounted for in our experiments.

RESULTS

Experimental results showed that, under our testing condition, at the end of seven days of submersion in the test solutions all cavity varnishes tested exhibited a loss of weight as compared to their weight before submersion (see figure). The control specimens showed no



Percent solubility of cavity varnish in vitro; seven-day results (mean ± standard deviation).

significant weight loss after being immersed in the solutions for seven days.

Radioactively tagged Universal varnish specimens showed a loss of the amount of radioactivity (DPM) after being submerged in the test solutions for seven days as compared to the DPM of the standard specimens before submersion. The test solution, in which the radioactively tagged specimens were placed, demonstrated an amount of radioactivity (DPM) nearly equal to that lost by the experimental specimens and representing the percent of solubility. Less than 5% of the radioactivity was unaccounted for in the experiments.

DISCUSSION

Two methods to investigate the solubility of cavity varnish were developed and used. The first method was based on the weight loss of the cavity varnish. A second method utilized a radioactive isotope; unfortunately, only one brand could be labeled because the formulas of the additional brands of cavity varnish were not compatible with our labeling techniques. The use of two methods did provide a cross-check or control to the study showing that by two methods the results were similar for varnishes in general.

Normal saline and Ringer's solution were selected as test solutions because they had been used in marginal leakage studies reported in the literature and because they are similar to body fluids and are used as replacement fluids.

Glass cover slips were used as specimens for weighing instead of extracted teeth or some other material. They provided a uniform surface area and added minimal weight to the specimen as compared to the weight of the varnish, thus providing more accurate results since the actual weight of the varnish was very small. Drying procedures before and after submersion in the test solutions were done to minimize weighing error due to water being released or absorbed by the varnish. A 3/4" x 1" frosted glass slide surface was used to provide a uniform area for the labeled varnish and also for ease in scoring and breaking the specimen to fit into the counting vial.

Our original protocol did not call for a direct comparison or evaluation of the individual varnishes. However, there was a notable difference between the varnishes comparable to the marginal leakage results in vitro reported by Murray and others (1983) and Sneed and others (1984); in other words, Copalite showed the least amount of marginal leakage of the varnishes tested.

It is recognized that the degree of solubility in vitro, with the varnish completely exposed to the test solution, is different from that in vivo when varnish is used under an amalgam restoration with the varnish partly protected by the restorative material as well as by tooth structure. However, the results are compatible with marginal leakage results reported in studies where various cavity varnishes were used under amalgam restorations and studied over a period of time (Murray, Yates & Williams, 1983). Furthermore, solubility of cavity varnish may account for increased marginal leakage observed in amalgam restorations of high-copper content in which cavity varnish is used, then observed over a period of time (Smith, Wilson & Combe, 1978; Sneed, Hembree & Welsh, 1984). There may be other factors, such as condensation force, proper placement of pins, defective enamel margins, and so on, that influence the marginal leakage of amalgam restorations (Going, 1972, 1979).

It is the author's opinion that although cavity varnish appears to be soluble with time it should continue to be used under amalgam restorations to help reduce early marginal leakage, reduce sensitivity of the teeth, and help provide protection to the dentin for as long as possible.

Acknowledgment

We are grateful to Dr Walter Stevens, associate dean for research at the University of Utah School of Medicine, for his assistance with the radioactive isotope labeling and advice on this project.

(Received 2 August 1985)

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BUONOCORE MEMORIAL LECTURE

Evaluation of Clinical Performance for Posterior Composite Resins and Dentin Adhesives

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Presented on 12 February 1987 by the senior author at the annual meeting of the Academy of Operative Dentistry in Chicago.

Part 1: Clinical Evaluation of Posterior Composite Resins

INTRODUCTION

Because of the supportive mechanical and physical data reported for composite resins, many dentists have placed occlusal stress-bearing restorations in posterior teeth in an attempt to fulfill the desires of their patients, others have become devout disciples of the "composite sect," while many admit to a degree of dissatisfaction and disappointment. It appears that a product capable of giving complete satisfaction in one operator's hands may prove a total disaster to another. Why? Because some dentists know the Achilles heel of composites and try to compensate for their unfavorable physical properties, such as polymerization shrinkage, resilience or wear, and that is the real solution to their usage.

Current composites may be classified as to

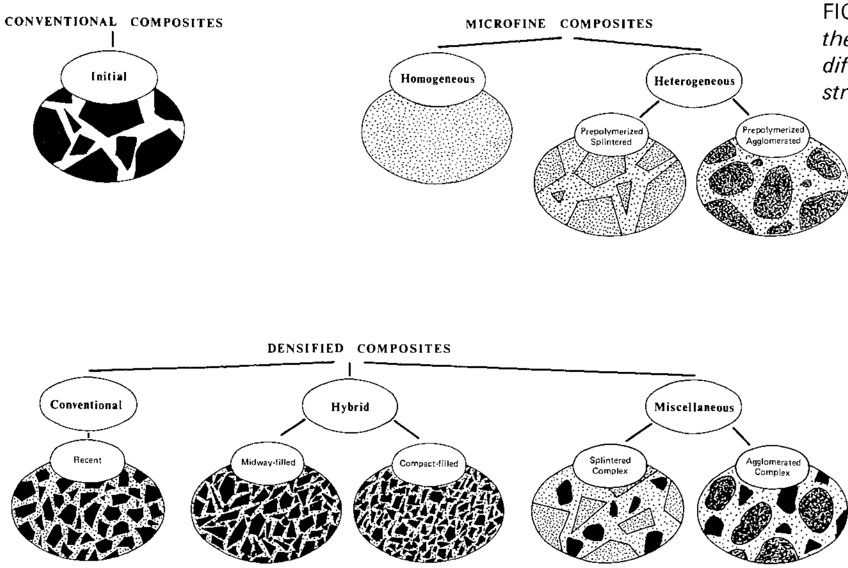


FIG 1. *Schematic presentation of the three groups of composites differentiated on the basis of their structure and mechanical behavior*

the type of matrix, polymerization, or filler (Fig 1) (Braem, 1985). The molecular structure and quantity of the different monomers as well as the quantity and type of filler used will affect the properties of the polymerized materials. Some materials are slightly stronger than others, some yield a smoother surface, and some possess a lower coefficient of thermal expansion.

The massive amount of data generated on the various competing products creates a bewildering task for the dentist to judge or rank materials according to their laboratory performance. Even if such ordering is performed, it will not necessarily reflect the clinical performance of the material.

The purpose of this paper is to discuss those properties that have obvious clinical relevance and affect the durability of the final restoration.

PHYSICAL AND MECHANICAL PROPERTIES

Viscosity

The viscosity of the composite resin has significant clinical implications and can vary from 18 to 1370 N/m^2 (Table 1). Posterior composite resins cannot be manipulated in the same way as amalgam. Composites are rather viscous, sometimes sticky, and cannot be condensed to create a firm interproximal contact area. The difficulty of establishing a good contact may allow mesial drifting of adjacent teeth, food impaction, and periodontal problems.

It is desirable to apply posterior composite resin with a syringe, but may not always be possible as these materials tend to have a high filler fraction which makes them very stiff and not suitable for syringe application. In some cases an amalgam carrier may be used to place the viscous, heavily filled composite.

The wetting ability and penetration coefficient of these condensable composites is low, and tends to induce void inclusion, bad adhesion, and an insufficient marginal seal. This

Table 1. Viscosity

	N/m^2	
Materials	at 23 °C	at 35 °C
Composite resins	18.1 - 1370	7.9 - 274
Bonding agents	19.7 - 28	8.5 - 11

problem may be solved with an intermediate enamel/dentin bonding agent that provides a better penetration coefficient and improved seal.

It is essential that the dentist adapt his methods to compensate for the problems associated with the viscosity of composites. It is generally agreed that separating teeth during cavity preparation — even before — and during the filling procedure is an absolute necessity for the realization of a proper contact area.

A simple procedure for pretreatment separation of teeth is the placement of an orthodontic elastic ring in a preoperative session. A fast but aggressive method of separation is the use of special Ivory separators (Columbus Dental, 1000 Chouteau Ave, St Louis, MO 63188) at the time of treatment. Another clinical technique for overcoming the problem of maintaining tight proximal contacts is to create space with the use of early wedging (Albers, 1985). During tooth preparation, both interproximal areas may be wedged to achieve maximum tooth separation. One wedge is removed while the other is placed more securely to maximize tooth separation at one proximal box. The composite is then condensed into the wedged and burnished areas of the wedged proximal box; care must be taken to condense and cure no more than a 1 mm thickness at a time. The wedge is then removed from the cured side and firmly placed interproximally at the site of the unfilled proximal box. The composite is added in a similar fashion to fill this box, followed by the final addition to complete the occlusal portion.

CURING SHRINKAGE

One of the most destructive forces of the composite resin-tooth structure bond is the stress induced by curing shrinkage. The polymerization reaction of the liquid resin components of a composite resin into a solid matrix results in polymerization shrinkage with measurements in vitro reported to range from 0.2 to 1.9% linear shrinkage and 1.2 to 4.5% volumetric shrinkage (Table 2).

The relatively high volumetric shrinkage of the hybrid composites (3.5%), as shown in Table 2, may need some explanation. Although higher filler contents might reduce the shrinkage to some extent, the maintenance of the

Table 2. Curing Shrinkage

Materials	Linear %	Volume %
Conventional composites	0.2 - 0.5	1.2 - 2.1
Hybrid composites	0.4 - 1.2	1.3 - 3.5
Microfilled composites	0.3 - 1.9	2.0 - 4.5
Unfilled resins	1.7	5.2

viscosity requires more TEGDMA diluent, which in turn results in more polymerization shrinkage than the larger bis-GMA molecules (Fig 2) (Ruyter, 1985).

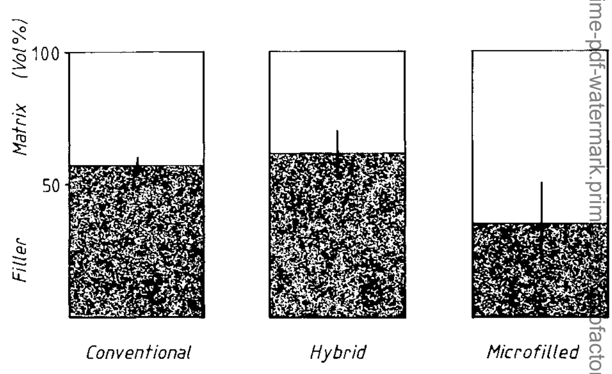


FIG 2. *Relative filler/matrix content (From Ruyter, 1985)*

The fillers in composite resins function to reinforce the polymer. The filler particles have a very high modulus of elasticity and tend to minimize the shrinkage. However, they do not prevent the build-up of internal stresses along the matrix-particle interfaces. In many cases, either adhesive and/or cohesive failure occurs. Adhesive failure results in the matrix pulling away from the fillers. Cohesive failure results in voids or microcracks within the resin phase (Davidson, 1985). This highly stressed material will be predisposed to degradation, leading to loss of surface layers. Polymerization shrinkage may be one of the main factors that determines the longevity of composite restorations.

In a nonbeveled preparation in which no acid-etch procedures or dentin adhesives are used, it is apparent that polymerization shrinkage has a direct effect on microleakage. An interfacial failure would result in marginal gaps between the restoration and the surrounding tooth structure with possible subsequent microleakage, bacterial invasion, pulpal sensitivity, thermal sensitivity, discolored margins, and secondary caries (Fig 3) (Albers, 1985).

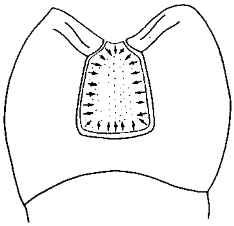


FIG 3. *Proximal view, depicting the contraction gap resulting from the polymerization shrinkage of a composite resin. (From Albers, 1985)*

Polymerization shrinkage is not usually a problem for small cavities when enamel etching is used. The adhesive forces on the margins of the cavity preparation are larger than the forces produced by the polymerization shrinkage; even though the restoration is strained, opening of the margin does not occur. If afterward the margins and the additional grooves are sealed with a fissure sealant, a leakproof restoration may be obtained.

When composite resin is placed in a large cavity, the mass to be polymerized is so large that the shrinkage forces prevail and produce a marginal opening, even when the enamel etching technique is used (Fig 4). Also, at the very

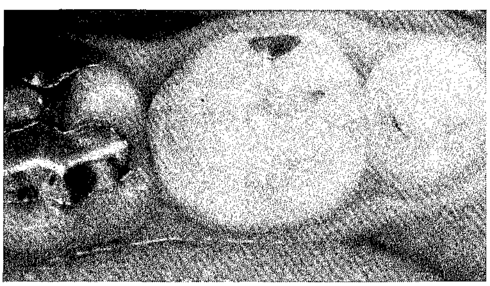


FIG 4. *Contraction gap at the buccal margin of a large MOD composite restoration in a first lower molar*

critical gingival margin area, the enamel required for etching is not available.

With the availability of bonding agents, reported to have improved bond strengths to enamel and dentin, the effect of contraction forces on tooth structure due to polymerization shrinkage deserves more consideration. When adhesion to the tooth surface occurs, internal stresses will develop. Contraction stresses of 2.8 to 7.3 MPa have been reported for composite resins (Davidson & de Gee, 1984). These polymerization stresses can produce cracks in the enamel (Figs 5 & 6). The fractures charac-

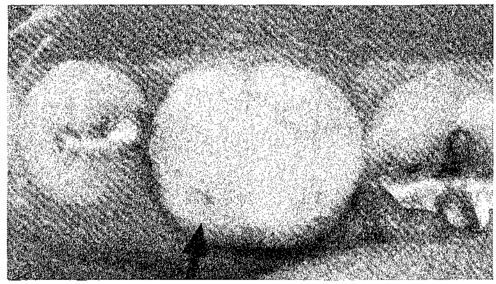


FIG 5. *The polymerization shrinkage can result in intercuspal tension on the bonded cusps and subsequent enamel crazing (lingual cusps of the first lower molar).*

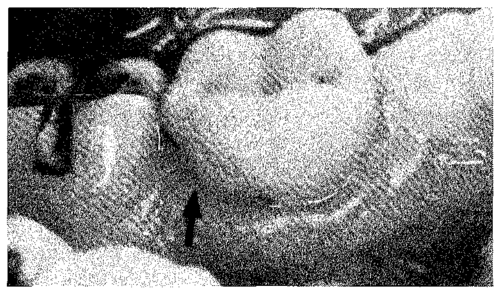


FIG 6. *Cracks in the enamel, caused by polymerization stresses in a large MOF composite restoration in a first lower molar*

teristically occur at the juncture of the middle and gingival third of the tooth (Fig 7) (Albers, 1985).

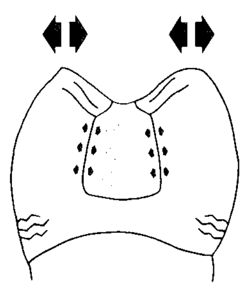


FIG 7. *A proximal view of the intercuspal tension, cuspal strain, and enamel crazing near the gingiva. (From Albers, 1985)*

The stress generated by polymerization is usually less than the tensile strength of enamel, which is about 20-40 MPa (Hegdahl & Gjerdet, 1977). But the larger the cavity and the larger the mass of the restoration, the more extensive is the shrinkage. Also, enamel is often compromised during cavity preparation and surface conditioning and may result in cohesive failure of the enamel adjacent to the restoration. While good marginal adaptation may be obtained initially (Fig 8a), the surrounding enamel wall may not be strong enough to resist the polymerization contraction forces if the restoration is large (Fig 8b). After 12 months these fractures crumble (Fig 8c). Such contraction

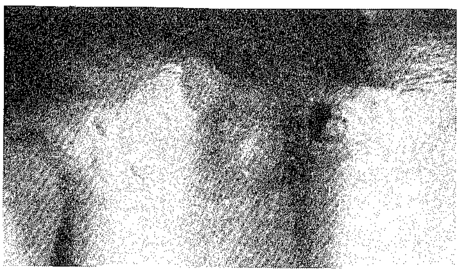


FIG 8a. *Baseline*

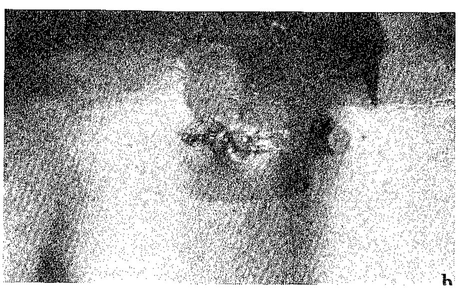


FIG 8b. *Six months*

FIG 8c. *12 months*

FIG 8(a-c). *Large cracks in the enamel may develop as a result of the polymerization shrinkage when the enamel walls are not adequately supported by dentin.*

forces may play a role in postoperative sensitivity, pain, or discomfort upon chewing.

Fortunately, in practice the stress can be relieved to a certain extent by flow to overcome the volumetric shrinkage and the wall-to-wall contraction. The use of counter dies or plastic foil is helpful for flow induction.

Concerning shrinkage, Davidson (1985) recently stressed the adverse relation of cavity design, preservation of adhesion, and preservation of surface contour. When the material is held firmly from all sides and the walls do not yield, the shrinkage stress can approach the values of the tensile strength of the material. Adhesion is challenged. The still unsolved polymerization contraction is the overpowering enemy in attaining adhesion.

The more shallow the cavity the better the possibilities of free contraction with flow toward the adhesive interface, allowing stress to be reduced and the adhesion preserved.

It is also clear that the composite restoration covered by tooth structure on all sides except one will be less exposed to wear than the restoration lying open from all sides but one. Here again we observe opposite interests regarding preservation of adhesion and preservation of anatomical shape. The conclusion can be drawn with respect to the two paramount variables — curing and cavity design. We cannot optimally serve both the preservation of adhesion and the anatomical shape.

Photoactivated composites contract toward the external surface of the restoration closest to the light source, in contrast to the chemically activated resins in which shrinkage occurs toward the center of the material. In both cases internal stresses are developed in the restoration (Krejci & others, 1986). Also, for photoactivated composites the degree of polymerization decreases as the distance increases from the surface nearest the curing unit. This results from the decrease of available photoactivating light intensity at increasing depths resulting from attenuation of the light in its passage through the composite. Incomplete polymerization in the depth of the restoration may lead to retention failures and adverse pulp tissue reactions.

To obtain optimal use of these photoactivated composites, success must be achieved through the application technique. It is important that shrinkage be directed toward the cavity wall and contraction toward the exposed surface must be avoided. It seems likely that the best way to maintain adhesion to the cavity floor is by incremental placement of light-curing composites. If the first increments are placed in such a way that free contraction and flow can proceed toward the dentin and are not obstructed by adverse (stronger) forces coming from the enamel-composite interface, the dentin-composite bond can gain strength (Davidson, 1985). The incremental technique is only practicable with light-curing composites because of their rapid curing. Layering with many small increments can minimize curing shrinkage, but requires much time and patience. The adhesion between subsequent layers is adequate, as there is a large number of reactive methacrylate groups to react with on the interincremental surfaces.

Douglas (1985) and Jensen and Chan (1985) evaluated shrinkage effects on teeth restored with posterior composite restorations by measuring cuspal flexure directly with strain gauges. These results indicate the strain on the tooth from polymerization shrinkage is greatly reduced by incremental polymerization and that the intercuspal distance is greatest with the single increment placement of the composite. Incremental placement of composite in an occlusogingival direction resulted in a reduced displacement, but the least change occurred when the composite was sloped up the cavity walls and cured in three increments.

Combining the transparent molar matrix bands and the proximal curing technique causes the material to contract toward the walls of the box cavity during light curing. Proximal curing must precede occlusal curing. Only after the proximals are completely filled should the occlusal portion be restored.

Recently a new product, Luciwedges (Hawe Neos Dental, Zurich, Switzerland), has been introduced to aid in the polymerization of the gingival portion of the restoration. These transparent light wedges have a reflecting core which radiates more than 90% of the light present at the curing tip in a lateral or proximal direction (Krejci & others, 1986). Since resin shrinkage vectors run toward the light source, the composite material shrinks in the direction of the gingivoproximal line angle. This results in significantly improved proximal margins.

When the above described measures cannot be utilized and the preparation is a relatively large MOD cavity, the clinician should consider the use of an indirect posterior composite inlay. Acceptable and stable margin behavior is only obtained with inlays luted with adhesive resin techniques. With the inlay technique the amount of composite material, present as a luting agent, being polymerized intraorally is very small; therefore shrinkage no longer creates an undesirable negative effect. However, this approach creates as many problems as it solves (Jensen & Chan, 1985).

RADIOPACITY

Composites used for class 2 fillings must be radiopaque for the following reasons (Roulet, 1987). (1) Diagnosis of secondary caries. The composite material must have at least a radiopacity slightly greater than enamel. If this is the case, demineralized areas on the cervical margin of the filling could be detected. (2) Diagnosis of overhanging margins.

Actually no clinically based data exist on the amount of radiopacity needed to detect secondary caries and overhangs in molars and premolars with high confidence. It should be kept in mind that with the addition of radiopaque fillers to composite resin, the wear behavior of composites is negatively influenced.

WEAR OF COMPOSITES

The important property of wear resistance of composites, which is a combined action of the physical and the mechanical properties of the material, needs consideration. With a computer-guided, three-dimensional measuring microscope, we measured the wear of four different products in premolar and molar regions. Adaptic (3M Dental Products, St Paul, MN 55144) was selected as a representative of conventional composites, Estic Microfill (Kulzer & Co, GmbH, Bad Homburg, W Germany) as the microfilled composite, and Miradapt (Johnson & Johnson, East Windsor, NJ 08520) as a hybrid posterior composite. Dispersalloy (Johnson & Johnson, East Windsor, NJ 08520) served as the reference amalgam for the posterior restorations (Lambrechts & others, 1984).

Our clinical experience with wear has shown that vertical substance loss is substantial, and that the substance loss is not homogeneous. Occlusal surface wear can be divided into two different areas — the occlusal contact area (OCA) and the contact free area (CFA). With respect to the wear mechanism, these two areas are distinctly different (Fig 9).

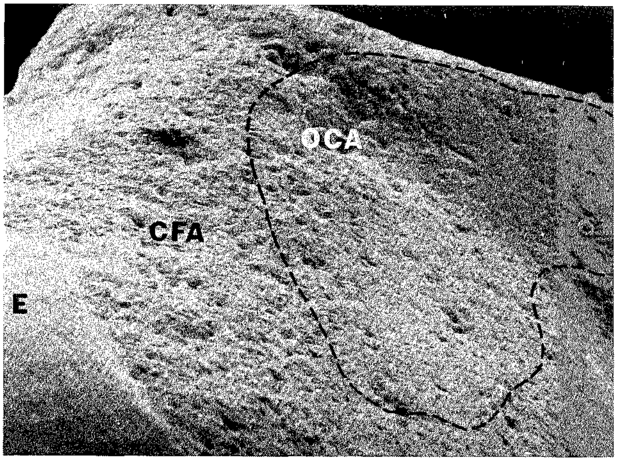


FIG 9. *Occlusal contact area* (OCA) *and contact free area* (CFA) *on an Adaptic restoration in posterior teeth* (E: *enamel)*

Attrition happens at the occlusal contact area and represents the loss of substance with facet formation as a result of direct tooth contact at the centric stop. Abrasion occurs at the contact free area and represents the wear caused by tooth brushing or by chewing food with no direct contact between the filling and the corresponding antagonist.

Figure 10 shows abrasion of all products tested over time. Dispersalloy was the most resistant, followed by Miradapt (Fig 11a,b) and

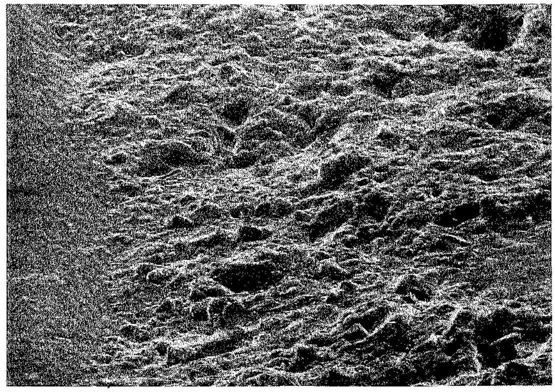


FIG 11(a,b). a: *Surface of a Miradapt restoration after four years in a contact free area. Some matrix wear can be seen with exposed filler.*

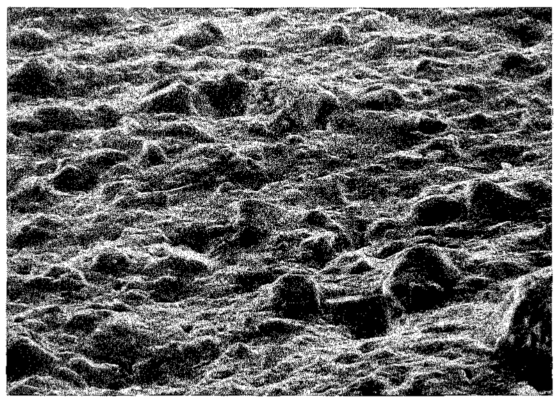


Figure 11b shows detail; exposure of fillers, but without microcracks in the matrix.

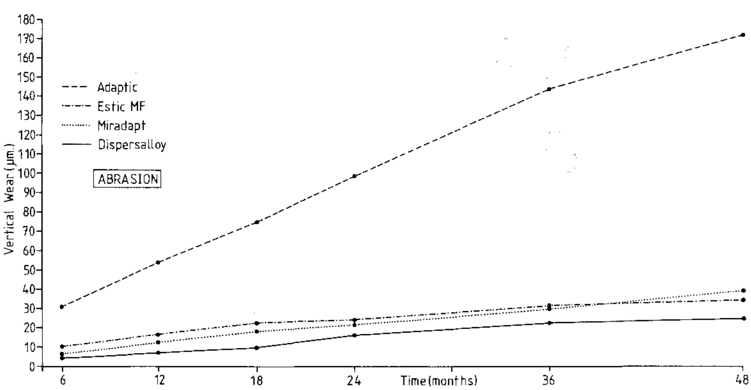


FIG 10. *Abrasion of all products over time*

Estic Microfill (Fig 12a,b). A low but steady rate of abrasion occurred. Adaptic (Fig 13a,b), as is well known, is very susceptible to abrasion and tends to wash out.

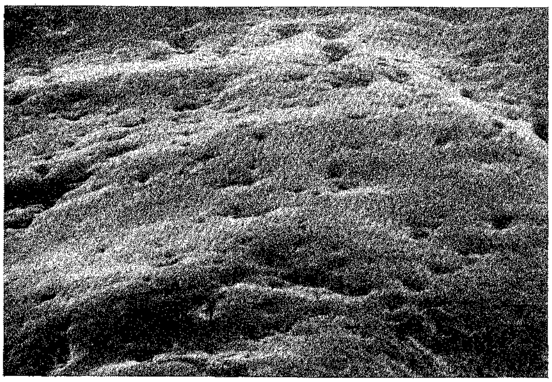


FIG 12(a,b). a: *Surface of an Estic MF restoration after four years in a contact free area. Because of the smooth surface, the microfilled composite systems are far less susceptible to friction wear.*

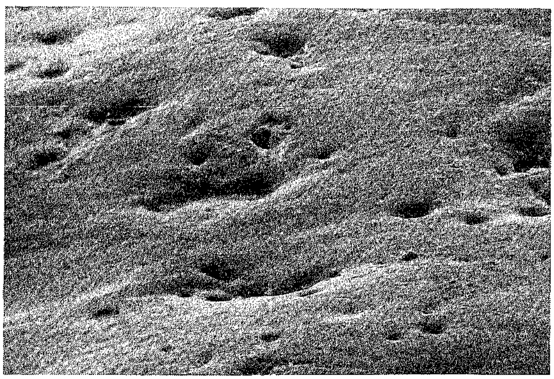


Figure 12b shows detail; pitting of the surface and polymerblock dislodgment.

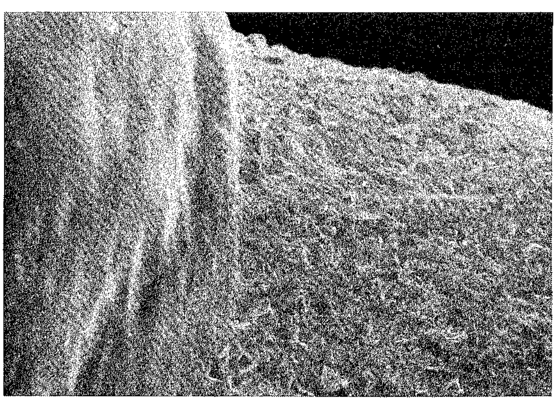


Figure 14 shows the mean attrition of all the products for the various control periods. Adaptic had the highest attrition, 425 μm at four years. The placement of the conventional com-

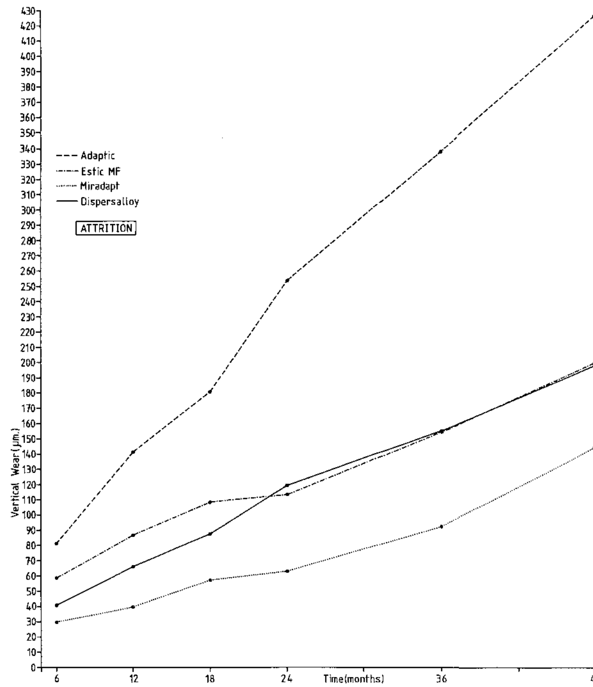


FIG 14. *Attrition of products over time*

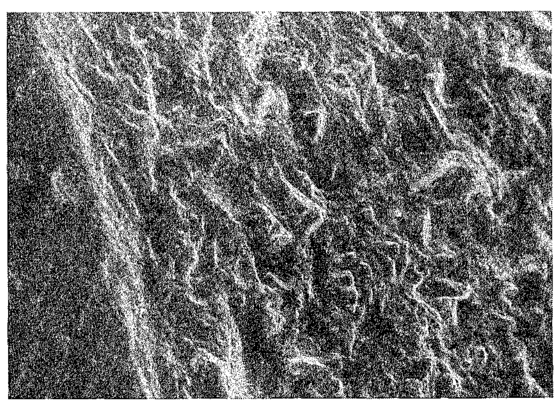


Figure 13b shows detail of exposed filler particles

FIG 13(a,b). a: *Abrasion wear of an Adaptic restoration in a contact free area with enamel wall exposure. A significant height of enamel wall was exposed and the filler particles protrude.*

posites in stress-bearing areas was shown to be insufficiently wear resistant and therefore clinically unacceptable. The attrition resistance of Estic Microfill was the same as reported for Dispersalloy, 198 μm at four years. Miradapt was shown to have better attrition resistance than amalgam, 143 μm at four years.

Figures 15a and b show an attrition site on a Dispersalloy restoration. At the attrition facet one can notice zones of smearing, pitting, and destructive creep.

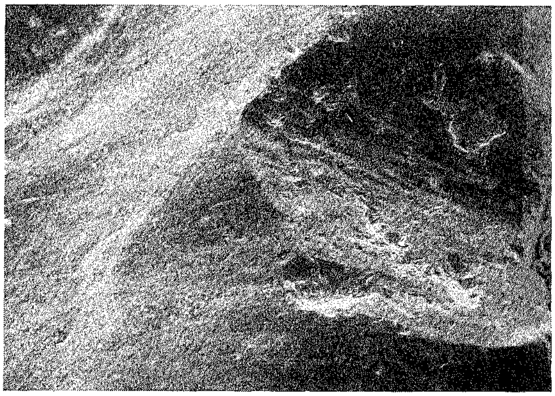


FIG 15(a,b). a: *Attrition scar on a Dispersalloy restoration*

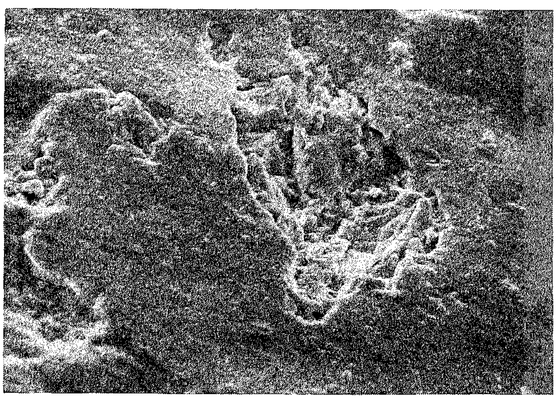


Figure 15b shows detail; smearing, pitting, and creep in the attrition area.

In Figure 16(a,b) the coherent attrition facet, in a Miradapt restoration, shows local filler pull-out but no sudden material breakdown. No real surface damage in the occlusal contact area occurred, indicating improvements in the character, form, size, and distribution of the inorganic filler increased the wear resistance of this so-called hybrid composite system.

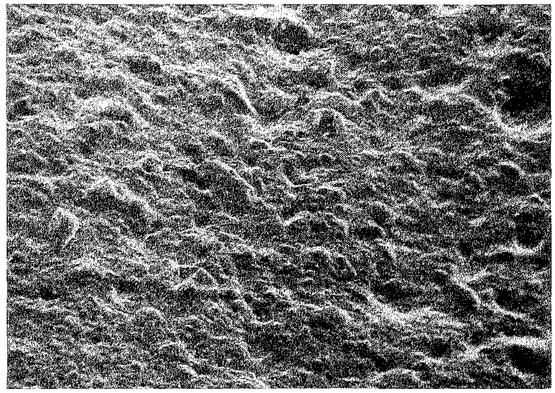


FIG 16(a,b). a: *Attrition zone on a Miradapt restoration after four years*

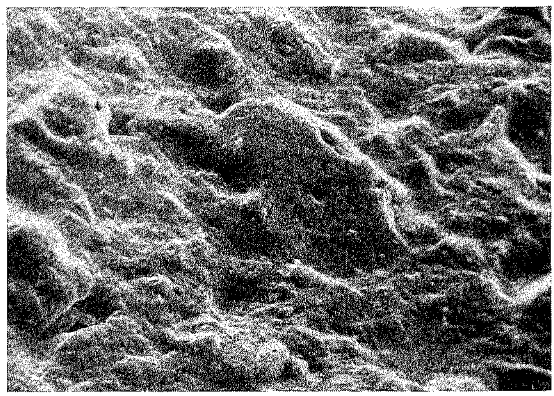


Figure 16b shows detail; no sudden material breakdown.

A number of the restorations in the study failed due to cyclic loading. It could be that material fatigue plays a major role in the wear behavior in such cases. Although Estic Microfill has a quantitative attrition resistance similar to that of Dispersalloy in our study, 20% of the Estic Microfill restorations failed after four years due to material fatigue.

The relatively inferior physical and mechanical properties of the microfilled composites may explain this fatigue sensitivity. The modulus of elasticity values for microfilled composites are substantially less than for the conventional or hybrid composites and are also more related to the volume fraction of filler than the strength values (Table 3). Materials with low filler contents, such as the microfilled materials (Table 4), are also more prone to mechanical deformation.

Table 3. Dynamic Young's Modulus under Flexure

Materials	GPa
Conventional composites	8 - 16
Hybrid composites	13 - 29
Microfilled composites	5 - 11
Unfilled resins	4
Amalgam	75
Enamel	82
Dentin	19

Table 4. Inorganic Filler Content

Materials	Weight %	Volume %
Conventional composites	75.5 - 79.0	53.0 - 63.0
Hybrid composites	68.1 - 86.0	49.8 - 69.6
Microfilled composites	29.1 - 66.1	17.1 - 49.1

The modulus of elasticity of the composite to be used in a stress-bearing area is an important property to consider, since a material with low modulus will deform more under masticatory forces. Such deformation could have catastrophic effects on the restoration and the surrounding tooth structures. Deformations could further increase the risk of microleakage. Therefore it seems reasonable to conclude that the usage of composites with low modulus of elasticity should be avoided in the posterior regions. The most appropriate modulus for a composite would be one comparable to that for dentin and cement bases.

Albers (1985) explains the destructive effect of cyclic loading of the microfilled composites as follows:

Shortly after placement, cracks begin to form in the resin matrix from occlusal stress. Microfilled composites deform under function, which further increases the strain on the resin matrix (Fig 17a). The corresponding scanning electron micrograph shows the formation of loose particles, attributed to surface fatigue phenomena (Fig 17b). Under function, the cracks begin to propagate from microcracks formed in the subsurface area (Figs 18a & 18 b). Cracks continue to propagate further, as with the weakening resin some of them are beginning to connect. At this point the microfilled composites appear to be performing satisfactorily since they show little wear (Fig 19a). The corresponding scanning electron micrograph shows that these microcracks propagate step by step in the subsurface area through areas of maximal shear stress (Fig 19b). The cracks will continue to propagate and connect in large numbers and will cause the eventual catastrophic failure of the restoration (Fig 20a).

This failure often occurs as a surprise to the clinician since the amount of wear seen prior to fracture was negligible. Severe destruction may occur (Fig 20b). This fatigue behavior makes it essential that restorations be followed over a long period of time to evaluate characteristics which occur over extended periods. It is dangerous to extrapolate good initial results and we must wait for at least four years to obtain clinical results we can trust for these posterior composites.

The hybrid composites offer a structural compromise between the wear-resistant conventional composites and the fatigue-resistant microfilled materials. This compromise produces an improvement in the character, form, size, and size distribution of the filler phase. Generally, these materials are as highly filled as possible with a wide range in filler particle sizes. Such high filler loads are reflected in the improvement of the average mechanical properties of these hybrid composites, as compared to the microfilled and traditional composites. The upgraded properties of the hybrids resemble those of dentin and lathe-cut amalgams. These changes favor the use of these materials to be extended toward the premolar-molar region, and this group of materials is now commonly indicated as the posterior composites of choice.

The number of composites indicated for use in the premolar-molar region, according to the manufacturer's product inserts, increases daily. The ultimate way to distinguish between these

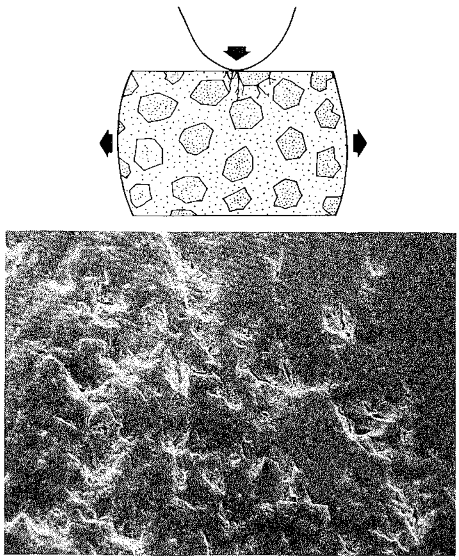


FIG 17(a,b). a: *Illustration shows how cracks begin to form in the resin matrix under occlusal stress (From Albers, 1985)*
Figure 17b - Corresponding SEM, shortly after placement

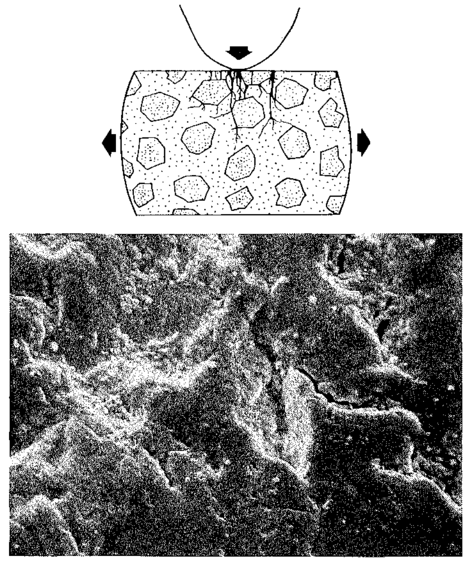


FIG 18(a,b). a: *Under function, these cracks begin to propagate, along and through the polymerblocks and matrix. (From Albers, 1985)*
Figure 18b - Corresponding SEM, one year after placement

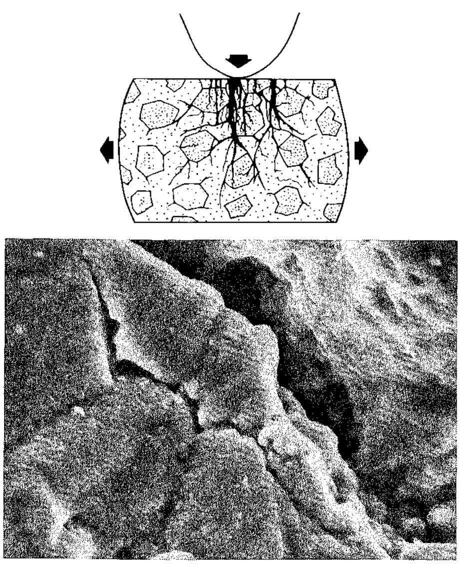


FIG 19(a,b). a: *Cracks continue to propagate and connect. (From Albers, 1985)*
Figure 19b - Corresponding SEM, two years after placement

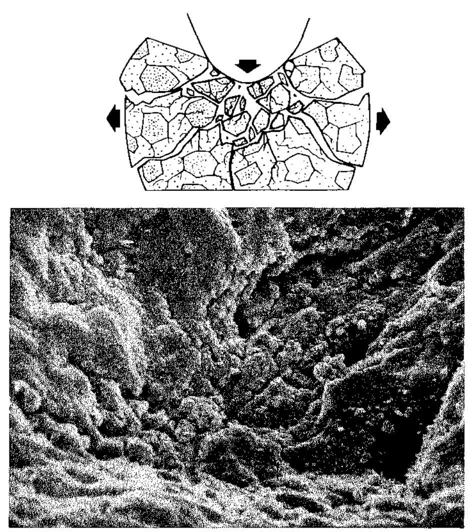


FIG 20(a,b). a: *Catastrophic failure of the restoration over extended periods of time. (From Albers, 1985)*
Figure 20b - Corresponding SEM, four to five years after placement

All scanning electron micrographs are of an Estic MF restoration in an occlusal contact area.

composites is to study their clinical behavior, and three years ago such an investigation was started with four hybridic constructed composites (Braem & others, 1986a). These were the self-cured P-10 (3M Dental Products, St Paul, MN 55144), the light-cured Estilux Posterior (Kulzer & Co, GmbH, Bad Homburg, W Germany), and two experimental formulations, one a light-cured type from the ICI Company (ICI Dental Division, UK), called Occlusin, the other a chemically cured type from De Trey Company, called Biogloss (De Trey, Zurich, Switzerland). Restorations were placed in mandibular first molars and evaluated by means of the same three-dimensional measuring technique (Lambrechts & others, 1984).

On contact-free occlusal areas, no differentiation between the wear of the four products could be made (Fig 21). Only the wear at occlusal contact areas allowed a differentiation between the products (Fig 22). The most attrition resistant turned out to be the self-cured product P-10, followed by the self-cured product from De Trey. The two light-curing materials, Occlusin and Estilux Posterior, seemed to be slightly less attrition resistant.

Phenomenologically, the wear mechanism of the hybrid composites differs from that seen in the microfilled composites as the cracks in the hybrids move through the matrix-phase and along the filler particles, resulting in a more localized destruction and an inherent crack-arresting or retarding mechanism (Fig 23a,b). Because of the higher filler load of these composites, they deform only slightly (Albers, 1985). Under function, these cracks propagate. Under

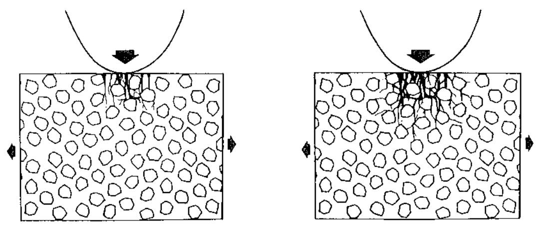


FIG 23(a,b). a (at left): *Shortly after placement, cracks begin to form in the resin matrix from occlusal stress. Hybrids deform only slightly under function; this reduces the internal stress on the resin matrix. (From Albers, 1985)*
Figure 23b (at right) *shows the cracks beginning to propagate under function.*

continued stress, the resin becomes weakened, favoring further crack growth (Fig 24a). Some cracks interconnect, and a part of the surface is worn away, leaving the characteristic pitted surface (Fig 24b). Pitting of the surface is an obvious result of such a wear facet and provides us with information which indicates the presence and consequences of subsurface

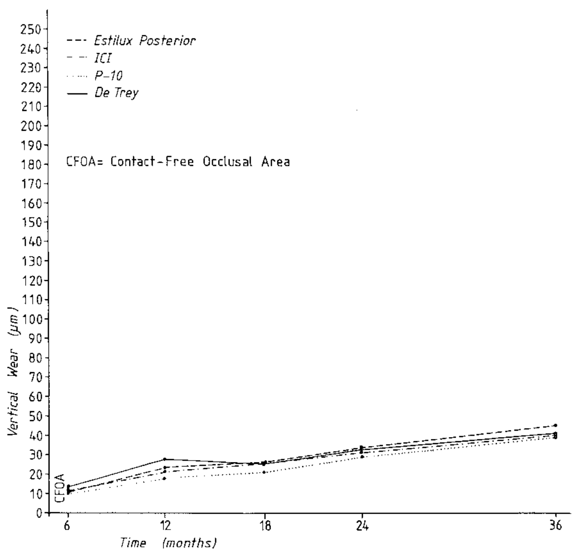


FIG 21. *Abrasion of products over time*

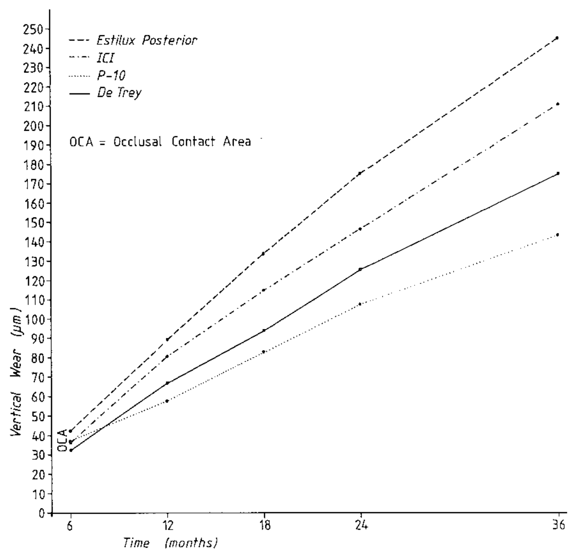


FIG 22. *Attrition of products over time*

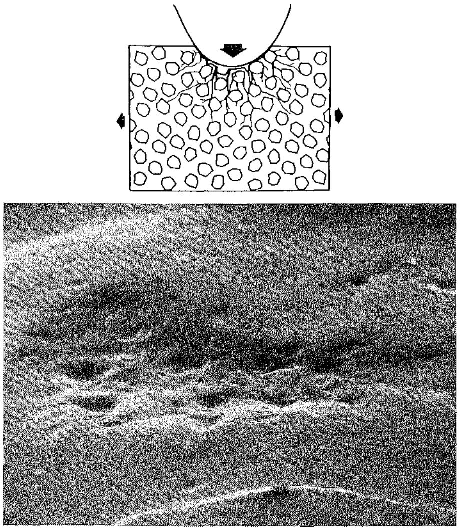


FIG 24(a,b). a (top): *Under continued stress, the cracks propagate further as the resin is weakened. (From Albers, 1985)*
Figure 24b is a corresponding SEM of Biogloss in an occlusal contact area after two years in vivo. Some of the cracks begin to connect and portions of the surface are worn away.

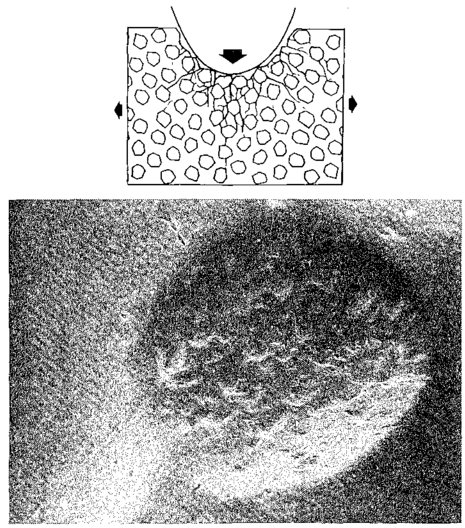


FIG 25(a,b). a: *As the resin weakens, the cracks continue to propagate and connect in large numbers, which will result in excessive wear. (From Albers, 1985)*
Figure 25b is a corresponding SEM of Biogloss in an occlusal contact area. The wear facets are sharply delineated.

damage as seen in a one- to two-year situation in vivo.

With continued time, further crack growth and excessive wear may result in failure of the restoration, although no such failure has been observed in vivo as yet (Fig 25a). However, the wear facet after three years shows rather severe destruction of the surface layer. It must be emphasized that the surface in the immediate vicinity of the facet remains virtually untouched by the wear process. Morphologically, the wear facets are sharply delineated as can be seen on this SEM (Fig 25b).

WEAR OF ENAMEL

Wear results should be compared to a wear standard. In the literature, amalgam is most frequently used as a reference, but one must recognize that amalgam itself is only a replacement of lost tooth tissues. Therefore, it seems logical to compare the wear of restorative materials with the wear of enamel, which also shows delineated wear facets. We measured the occlusal contact wear of enamel on premolars and molars.

Figure 26 shows the slope of the wear curve

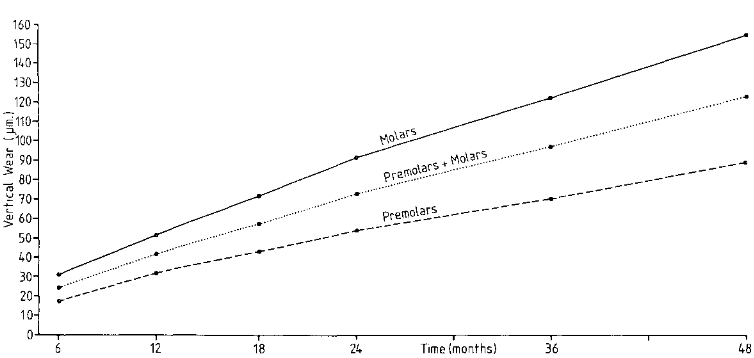


FIG 26. *Wear curves on the occlusal contact area of enamel in premolars, molars, and in the combination premolars plus molars. Vertical wear in micrometers over a period of four years.*

on the occlusal contact area of enamel to enamel in premolars, molars, and in the combination of premolars plus molars. Figure 27

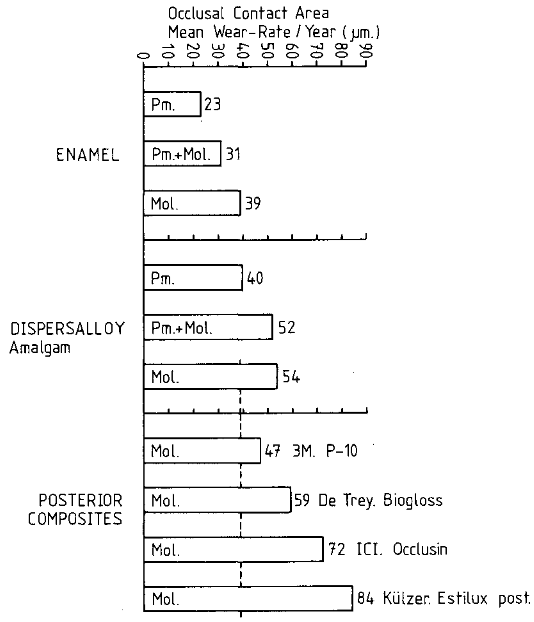


FIG 27. *Average in vivo wear rate of enamel on occlusal contact areas in relation to amalgam and posterior composites*

shows the average wear rate in vivo of enamel in relation to amalgam and posterior composites at occlusal contact areas, expressed in µm/year. For molars it is about 39 µm/year, 23 µm for premolars, which is significantly lower, and 31 µm for the combination. Posterior filling materials should be able to meet criteria for placement in molar teeth. However, it can be seen that the wear resistance, comparable to enamel, is not yet reached. The wear rate for amalgam (Dispersalloy) measured in molars amounts to 54 µm/year.

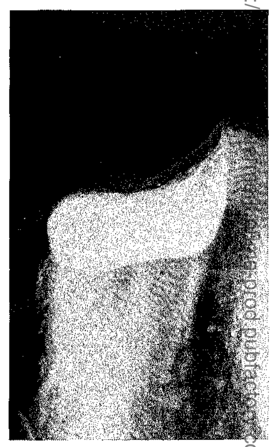
Another important finding is the excessive wear on natural tooth structure by opposing posterior composite restorations. Quartz-filled composites such as Adaptic may act as abrasives. Figure 28a shows the tooth at baseline, and Figure 28b shows the results after four years. The sharp edges of quartz crystals are much harder than enamel and contact may

28a. *Baseline*

28b. *Four years later*

28c. *Occlusal view*

Detail in an SEM may be seen in Figure 29.



28d. *Vestibular view of the wear scar after four years*

FIG 28(a-d). *Stereomicroscopic pictures of the enamel wear caused by opposing Adaptic restoration used as posterior composite.*

have had an abrasive sandpaper-like effect on the opposing dentition (Fig 28c,d).

It is clear that the large size of the hard-filler particles have caused wear scratches by their impacting and grinding on occluding enamel (Fig 29a,b & c). Extreme care must be taken to evaluate the probable effect of using certain restorative posterior materials which will oppose existing tooth structure (Chapman & Nathanson, 1983).

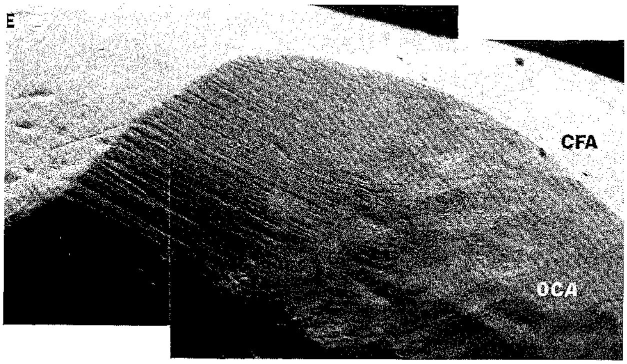
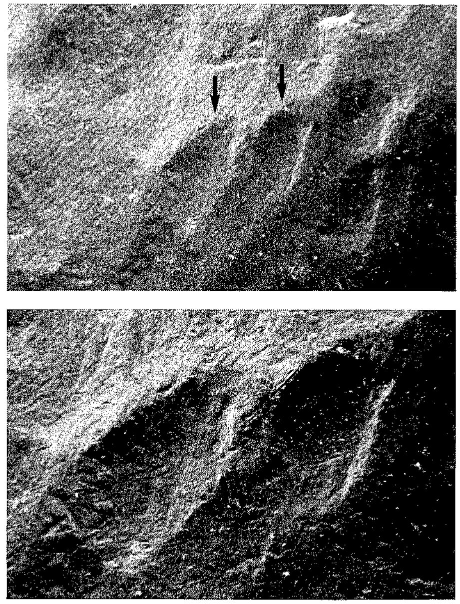


FIG 29(a,b). a: *SEM of Figure 28c; wear scratches at the border and impact zones in the center of the occlusal contact area* (OCA) *on enamel, caused by opposing Adaptic restoration. (E: enamel, DFA: contact free area)*



Figures 29b and 29c show detail of the impact zone.

COMPRESSIVE STRENGTH AND TENSILE STRENGTH

The compressive strength is substantially higher than the tensile strength of composites (Table 5); however, its clinical significance is unknown, as no clinical data are available which would indicate that high compressive strengths are required to resist occlusal forces. Nonetheless, it is wise to avoid placement of these materials in stress-bearing areas. Occlusal contacts should be supported by enamel in spite of the placement of a restoration. Another important topic is that of beveling. Antagonistic occlusal contacts must be checked before beveling. If the beveling process extends the margin to an area of contact with the opposing tooth, it results in the composite being placed in function, and as the composite is weaker than the tooth the probability for chipping of the restoration is increased. Finally, when the cavity preparation does not provide sufficient space for a bulk of composite, amalgam-like isthmus fractures may occur.

Table 5. Tensile Strength (Direct Pulling)

Materials	MPa	x	Compressive Strength MPa
Conventional composites	31 - 33	x6 - x8	187 - 246
Hybrid composites	24 - 41	x12 - x16	324 - 402
Microfilled composites	17 - 33	x13 - x16	234 - 284
Unfilled resins	22	x3	72

YOUNG'S MODULUS

Despite the explosion of research in the field of dental materials science, the minimum acceptable strength required for posterior restorative materials has not been established. Therefore we theorized that Young's modulus or the modulus of elasticity could be a very sensitive parameter for evaluating and ranking posterior composites. A new method for nondestructive testing of the elastic modulus was developed (Braem, 1985; Braem & others, 1986b). A rectangular composite sample is supported at its nodal zones. A reproducible shock excitation is obtained by a metal ball soldered on a one-sided clamped blade spring that is released from a solenoid coil. The free oscillating body tends to reach its fundamental vibration mode. The vibration is detected by a microphone in an anechoic test chamber, the signal fed to a special signal analyzer (the Grindo-sonic); the basic period of the oscillation accurately measured, the frequency calculated, and the Young's modulus is derived. The Young's modulus of 56 different dental composites was determined in this way. In Figure 30 the so-called posterior

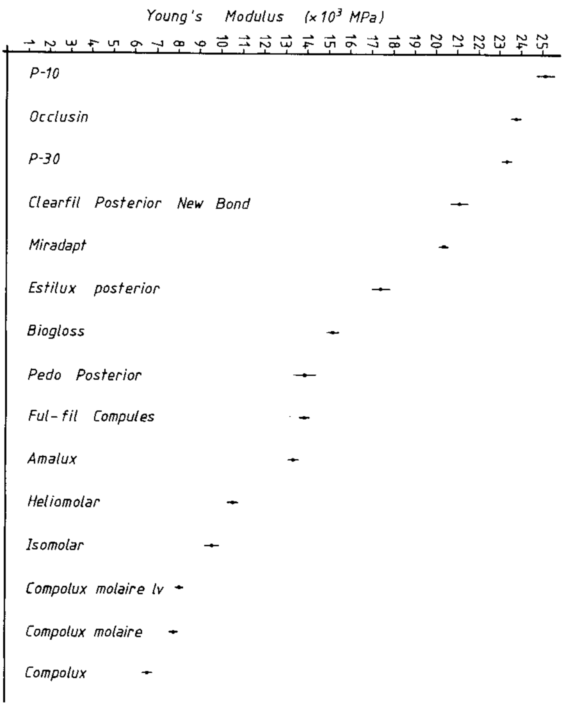


FIG 30. *The Young's moduli of the composites marketed as posterior material (From Braem & others, 1986b)*

composites were selected. It is easy to recognize that the spread within the posterior composite group is very large, ranging from 7700 MPa for Postilux to 25 000 MPa for P-10. Very highly filled composite resins are said to be suitable for posterior occlusal load-bearing restorations. Even if their modulus of elasticity is much lower than that of amalgams, it seems that 25 000 MPa which are obtained with highly filled materials give the composites enough rigidity so as not to be deformed under physiological occlusal forces. That's perhaps what makes P-10, Occlusin, J&J Experimental, and P-30 so interesting, as they behave very well clinically.

More interesting than the absolute E-modulus is the change it undergoes during polymerization. We investigated the evolution in Young's modulus for both self-cured and light-cured composites as soon as possible after mixing or exposure to the light source until 24 hours later. A striking finding is that for most self-cured materials, at about 10 minutes after the mixing, only a fraction of the final Young's modulus is reached. The behavior of the light-cured composites is also different depending on the product; however, the increase in Young's modulus is much faster, approaching the 24 hours-value after only 10 minutes (Braem, 1985). The low values obtained in the time period immediately following the start of the curing reaction represent a vulnerable condition of the matrix-phase and emphasizes the potential for damage which may be inflicted on a freshly placed composite restoration during finishing or polishing. It should be advantageous to advise the patients to treat the restoration with care during this period.

We also tested changes in the E-modulus with long or short illumination times. The results differ according to the product. Estilux Posterior, when cured twice for 60 seconds, attained an E-modulus of 17 200 but when cured for 20 seconds as the manufacturer recommends, the E-modulus was only 7600, which was less than half the maximum attainable strength. Occlusin and P-30 seem to be less influenced by shorter illumination times, which demonstrates their well-functioning catalyst system and superior chemistry. If all composite resins are cured for 60 seconds, the potential is significantly better for achieving maximal physical properties.

COEFFICIENT OF THERMAL EXPANSION

The coefficient of thermal expansion may vary considerably, depending on the quantity of inorganic filler present (Table 6). For some microfilled products, containing only 35% or less inorganic filler, the value can be as high as 70 x 10^{-6} °C as compared with a value of approximately 35 x 10^{-6} °C for a heavily filled hybrid composite and around 10 x 10^{-6} °C for

Table 6. Linear Thermal Expansion Coefficient

Materials	x 10^{-6} °C
Conventional composites	25.3 - 34.6
Hybrid composites	25.8 - 44.1
Microfilled composites	49.2 - 69.3
Unfilled resins	80.0 - 90.0
Amalgam	19.0 - 25.0
Enamel	11.4
Dentin	8.3

tooth structure. If a significant mismatch between resin and tooth substance exists, thermal cycling may cause microleakage by percolation of fluids down the interface.

THERMAL DIFFUSIVITY

When considering thermal expansion and contraction effects, the thermal diffusivity values of the materials should be taken into account since thermal stimuli occurring in the mouth are transitory in nature (Table 7). It follows that, although dental amalgam has a relatively low value of coefficient of thermal expansion (25 x 10^{-6} °C), it expands and contracts rapidly when subjected to a thermal stimulus owing to its relatively high thermal diffusivity.

Table 7. Thermal Diffusivity

Materials	mm^2/sec
Conventional composites	0.625 - 0.670
Hybrid composites	0.211 - 0.232
Microfilled composites	0.155 - 0.210
Unfilled resins	0.125
Amalgam	9.6
Enamel	0.469
Dentin	0.183

WATER SORPTION

Water sorption is one of the properties impacting on the clinical durability of a restoration. The microfilled composites show the highest water sorption (Table 8). Mechanical

Table 8. Water Sorption

Materials	Weight %	Volume %
Conventional composites	0.2 - 0.8	1.5 - 2.0
Hybrid composites	0.2 - 0.6	0.4 - 1.6
Microfilled composites	1.2 - 2.1	2.0 - 3.1

properties are affected by sorption of water which acts as a plasticizer and stress corrosion agent, weakening the particle matrix interface. Water sorption increases with the volume of the resin phase although there may be some filler interactions. Localized swelling at the filler interface and debonding may lead to hydrolytic breakdown. Söderholm and others (1985) have demonstrated leaching of ions from filler particles and interfacial microcracks. It is reasonable to suspect that a debonding due to hydrolytic degradation or slow crack growth could be a major clinical problem.

CONCLUSION

It seems reasonable to suggest that the trend toward posterior composites should proceed with caution. Instead, more knowledge must be gained regarding the stability of the filler-matrix bond of a dental composite in a wet environment until posterior composites can be considered to be a reliable therapy.

However, some posterior composites can provide esthetically and mechanically acceptable restorations in small class 1 and class 2 cavities. In large cavities, one can expect problems due to shrinkage, loss of adhesion to dentin, fracture, fatigue, and wear. Thus composites cannot replace amalgam completely.

Part 2: Clinical Evaluation of Dental Adhesives

INTRODUCTION

Bonding to dentin has presented a problem that has long resisted solution. Only within the last two years has real progress been made in this area (Asmussen, 1985).

Acid etching the dentin surface removes the smear layer and opens the dentinal tubules. Upon application of a low-viscosity monomer, the monomer penetrates into the tubules where polymerization takes place. This mechanical interlocking does not in itself provide adequate bonding to dentin and must be supplemented with chemical bonding.

Dentin adhesives may react with dentinal surfaces to form a chemical bond accordingly to two main modes of operation, bonding either to the inorganic or organic constituent or both. The adhesive molecule of Buonocore and others (1956) was designed to bond to the calcium ions of dentin through a phosphate group as the active group. Several products are now commercially available that rely on a bond with the inorganic constituent of the dentin.

In Copenhagen, Asmussen and Munksgaard (1985) used another approach and investigated the possibilities of bonding to the organic constituent of dentin, mainly collagen. They used an aqueous mixture of glutaraldehyde and HEMA (termed GLUMA). Since water is always present on the surface of dentin, an adhesive that would operate in an aqueous environment would be interesting. With the use of GLUMA, a strength of bond to dentin of approximately 18 MPa was obtained, which is very close to the approximately 20 MPa achieved with the acid-etched enamel technique.

MATERIALS AND METHODS

One of the best clinical sites in which to evaluate the effectiveness of dentin adhesives are those cervical lesions caused by toothbrush abrasion or erosion. These lesions are commonly smooth and noncarious, but can be sensitive to touch or temperature changes, and have an unesthetic appearance.

A team of five dentists placed 276 restorations in three different ways (Vanherle & others, 1986; Braem, Lambrechts & Vanherle, 1986c) (Fig 31 & Table 9).

Table 9. Filling Techniques Used

	Method		
Group	Preparation	Bond	Composite
A	Butt joint	Scotchbond	Silux
B	Feather edge + etching	Scotchbond	Silux
C	Feather edge + etching	Enamel-Bond	Silux

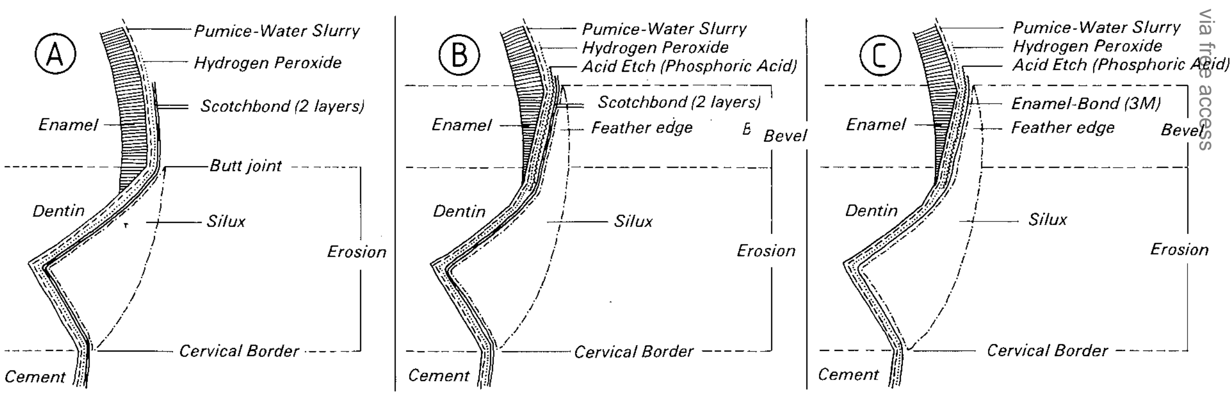


FIG 31. *Treatment procedures for the three groups*

In the first group, Group A, the morphology of the lesion was not changed. The erosion lesion and adjacent enamel were cleaned with a pumice-water slurry and hydrogen peroxide. Two layers of Scotchbond were applied followed by the placement of Silux. The restorations were finished with a butt joint.

In the second group, Group B, the enamel wall was beveled and acid etched and two layers of Scotchbond (3M Dental Products, St Paul, MN) applied on both the enamel and dentin surfaces, followed by the placement of Silux (3M Dental Products). The restorations were finished to a feather edge.

In Group C, the enamel was beveled, acid etched, and the Enamel-Bond (3M Dental Products, St Paul, MN) applied, followed by the application of Silux (3M Dental Products).

Evaluations were performed after six months, one year, and two years. Marginal adaptation was evaluated clinically with a mirror and probe and by the use of scanning electron micrographs. An index system was used to record the results (Vanherle & others, 1986).

RESULTS

In Group A, only 4% of the fillings showed an excellent marginal adaptation after one year (Fig 32) and this group exhibited the highest percentage of lost restorations (Fig 33). Although the percentage of excellent margins was higher in Group B (Fig 32), the percentage of lost fillings in Group B was 14.5% versus 2.5% in Group C (Fig 33).

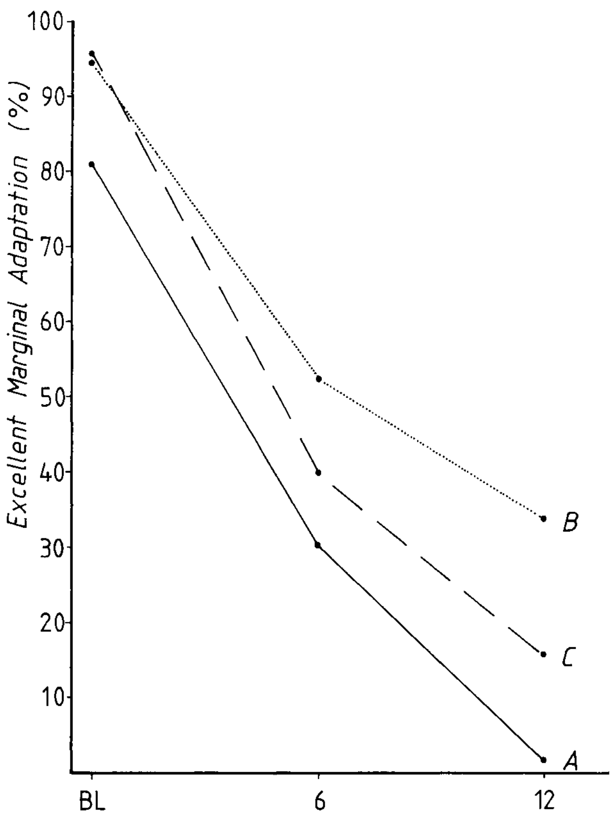


FIG 32. *Percentage of excellent marginal adaptation in the different groups at baseline, six months, and one year*

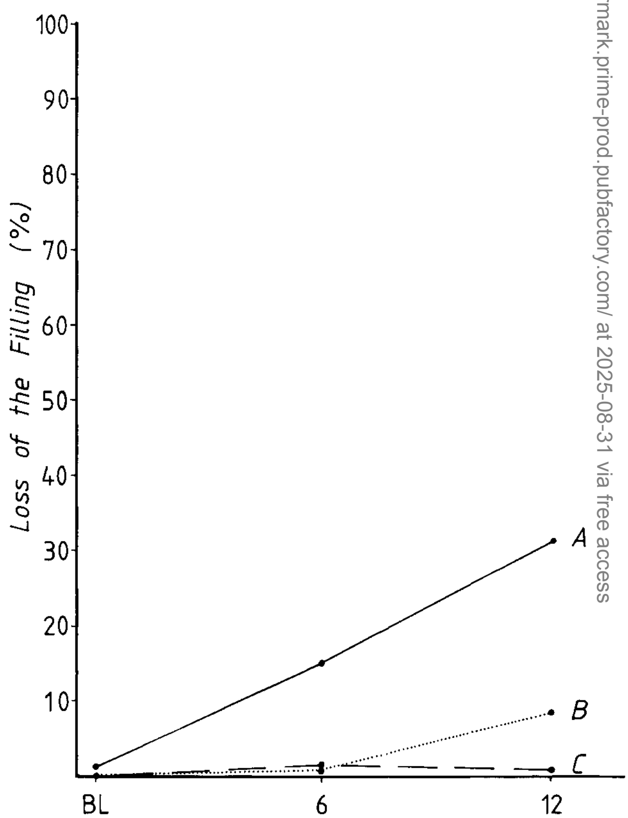


FIG 33. *Percentage of lost fillings in the different groups at baseline, six months, and one year*

A special code was developed to distinguish failures on the enamel or cervical margins (Fig 34) (Vanherle & others, 1986). The highest per-

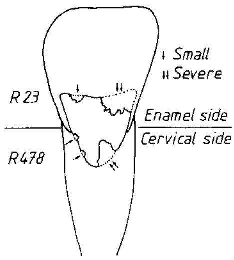


FIG 34. *Special codes for defects at enamel and cervical surfaces. (From Vanherle & others, 1986)*

cent of cervical defects was demonstrated in Group C. On the enamel surface, Groups B and C recorded comparable results while Group A had the highest percent of defects (Fig 35). These findings are also shown in the clinical photographs and the SEMs (Braem & others, 1986c).

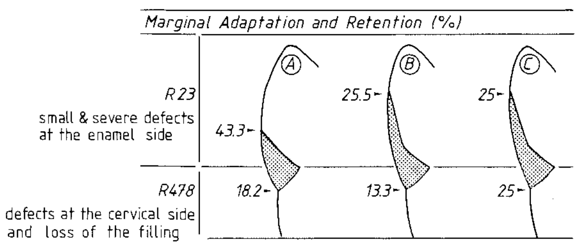


FIG 35. *Marginal adaptation and retention (percent) (From Vanherle & others, 1986)*

Group A revealed the most defects. Figure 36a shows restorations at the baseline; Figure 36b shows the control after six months. The presence of gaps and steep margins strongly suggest that debonding occurred or that lack of bonding would be responsible for marginal leakage. Steep margins retain and favor plaque accumulation with marginal staining and recurrent decay.

For Group A restorations the occlusal margin was often characterized as partially debonded, there being a gap between the restorative material and the tooth. Continued undermining of the unsupported material led to crack formation. Minimal forces were capable of fracturing marginal edges. Such degradation and subsequent breakdown resulted in steep marginal edges and these borders were prone to plaque accumulation and caries recurrence.

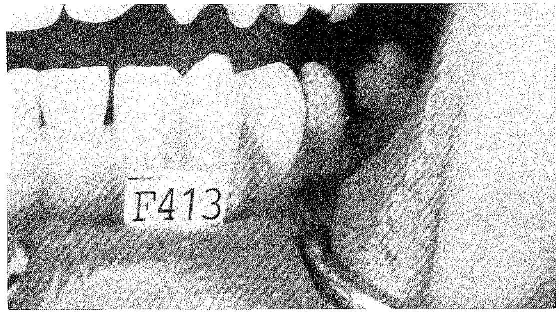


FIG 36(a,b). a: *Group A restorations on 20 and 21 after filling procedures*

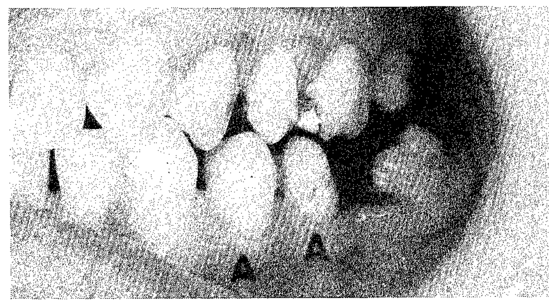


Figure 36b shows several marginal defects and staining at the butt joint after six months.

In some cases the use of Scotchbond resulted in clinically acceptable marginal adaptation at the cervical wall, while in other cases the restoration in Group A extruded out of the cavity and showed cervical debonding. Defective and catching occlusal margins, together with doubtful cervical adhesion, can be the cause of early loss of the restoration (Fig 37). Examination of the dentinal surface for composite remnants shows that the same adhesive failures occurred where the only remnants found were at the

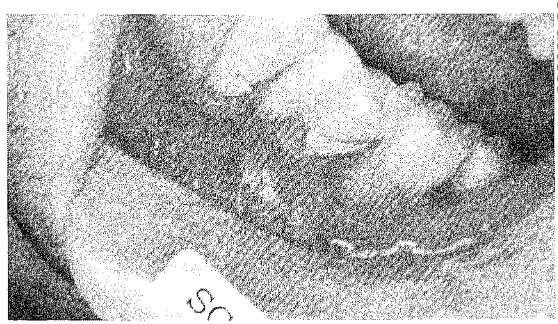


FIG 37. *Total debonding of Group A restorations on 20 and 22 after six months*

enamel border of the lesion. Convincing evidence of a strong bond could not be found. These results indicate that the sole application of Scotchbond was inadequate and would not guarantee success. The best results were obtained in Group B, where a long bevel of enamel was made and etched prior to the application of Scotchbond. This veneering technique offered increased retention and stabilization.

Figures 38a and 38b show a clinical case of

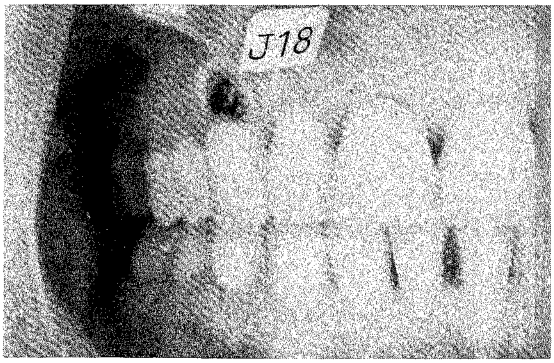


FIG 38(a,b). a: *Preoperative condition of the upper right side*

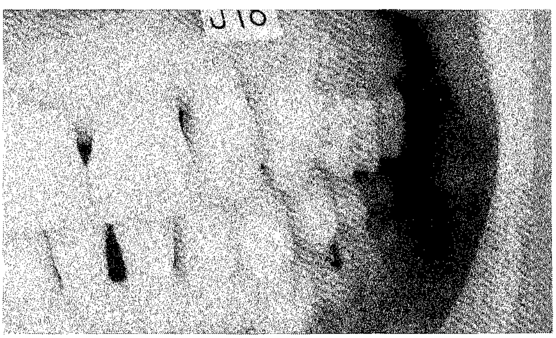


Figure 38b, upper left side

multiple cervical lesions that were later restored according to technique B. Figures 39a and 39b show the postoperative frontal view: left side and right side.

Figures 40a and 40b show the postoperative proximal view, left side and right side. Notice the beneficial effect of the veneering technique regarding esthetics and retention efficiency. The combination of feather edge, acid etching, and Scotchbond provides ideal marginal adaptation.

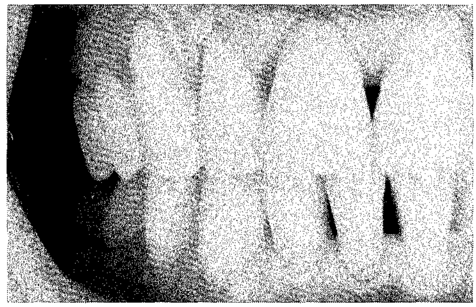


FIG 39(a,b). a: *Postoperative condition, according to Group B, of the upper right side*

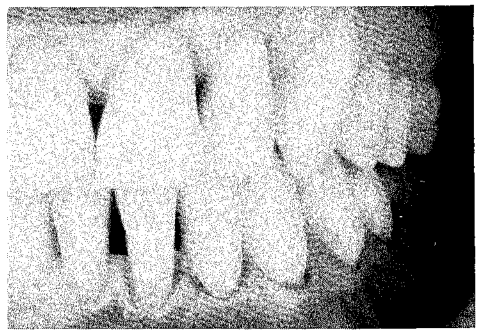


Figure 39b, of the upper left side

FIG 40(a,b). a: *Postoperative condition, according to Group B, of the upper right side (mirror view)*

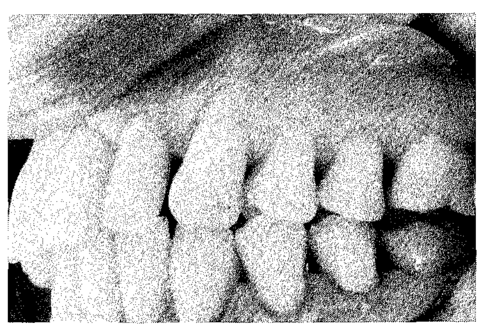


Figure 40b depicts the upper left side. Note the beneficial effect of the feather edge and veneering technique.

A rougher surface with numerous extruding fillerblocks were sometimes found in the mesial and distal portions of the restoration (Braem & others, 1986c) and could be a consequence of the difficulty to reach interproximal regions with the light beam and finishing or polishing instruments, causing protruding fillerblocks, rougher areas, and increased staining. Another important feature observed was that due to the extensive surface finishing required for feather-edged restorations, where the overlaying feather edge of resin may become too thin to resist the physiologic forces applied, loss of the restoration resulted. This applied specifically to the middle third of convex vestibular surfaces. With these types of failures the benefit of beveling, acid etching, and veneering was lost.

Restorations placed according to technique C, where the enamel bond was used, exhibited a considerable number of cervical defects, gaps, and marginal fractures (Fig 41). The

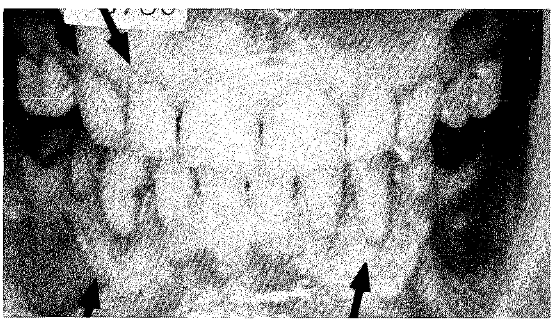


FIG 41. *Group C restorations show several marginal defects, leakage, and staining at the cervical area after one year*

Enamel-Bond system of Group C favored leakage at the cervical cavosurface of the restoration. Ten percent of the Group C restorations showed caries after one year (Table 10). Often

Table 10. Caries Recurrence

	Acceptable Results (%)		
Group	Baseline	6 Months	12 Months
A	100	96.9	97.5
B	100	98.9	100.0
C	100	92.5	89.6

patients complained about persisting sensitivity, especially when they touched the restoration, and generally indicated a leaking restoration. When the restoration is pressed against the dentin, hydrodynamic pressure is transmitted through the tubules to the pulp, causing pain and pulp hyperemia.

DISCUSSION

Adhesion to dentin is a complex chemical and physical process, not fully understood at this moment. Several factors play an important role.

One factor is the dentin surface which is hydrolitic in nature and has a low surface energy. After cavity preparation, it is covered with a smear layer and a proteinous exudate. The Ca content is dependent on the depth of the cavity, the caries attack, eating habits, acid treatment, the presence or absence of the smear layer, and finally, the application of mineralizing solutions. In the clinical environment, a bond was difficult if not impossible to obtain when the eroded surface was old and smooth; however, a slight roughening of the sclerotic dentin surface improved the bond remarkably.

An explanation for cervical leakage and loss of the restoration is the dimensional change due to polymerization shrinkage which is directed toward the enamel composite interface (Fig 42a) (Albers, 1985). Davidson and de Gee

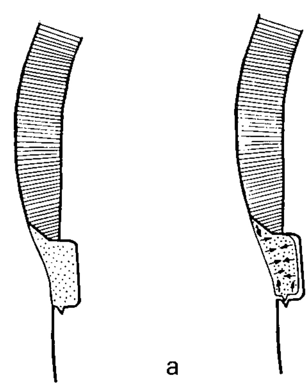
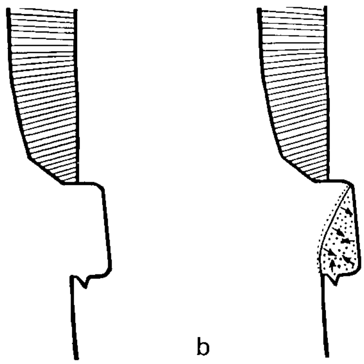
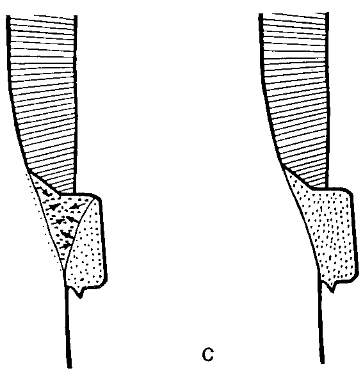


FIG 42(a,b,c). *Three views of the buccolingual cross-section view showing the contraction gap in a dentin-enamel class 5 composite restoration with enamel and dentin margins. (From Albers, 1985)*
42a: *One-phase technique*

(1984) showed the bond strength to dentin to be lower than the three-dimensional shrinkage stress of the resin. The shallower the cavity the better the chance of free contraction and flow toward the adhesive interface. Measuring the linear polymerization stress, Davidson and de Gee obtained values of 3.9 MPa for Silar, which is lower than the bond strength to dentin. Reduction of stress, and thus conservation of adhesion, is a function of cavity form, the application technique, and the material used. Therefore, they advocate an incremental build-up technique with a light-curing composite resin (Fig 42b,c).



42b: *Two-phase addition. Composite is always cured on the dentin first.*



42c: *Two-phase addition. The second increment is placed on the enamel and on the first portion. A contraction gap will not be as likely to open at the gingival margin.*

It is very important that before a cervical lesion is restored with the acid-etch technique and dentin adhesives, the etiology of the lesions must be considered. Lee and Eakle (1984) found that eccentric loads applied to the occlusal surfaces of teeth generate stresses that are concentrated in the cervical regions (Fig 43a).

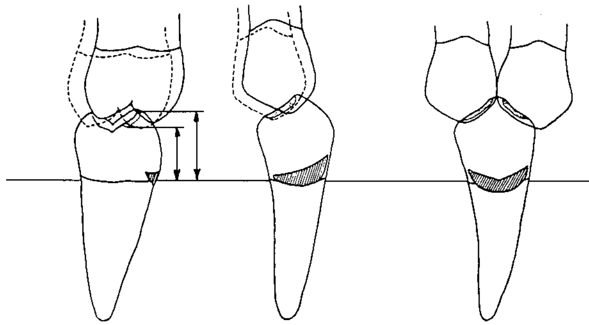
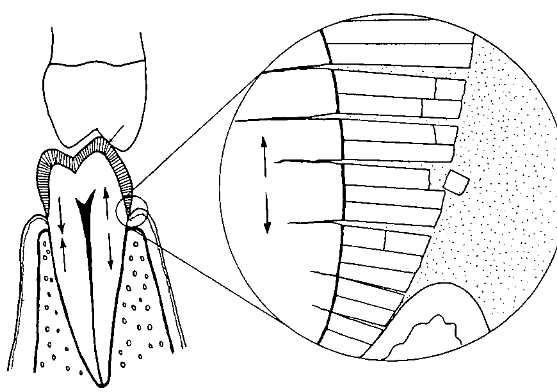


FIG 43(a,b). a: *Proximal view shows teeth functioning along a contact plane. Facial view shows morphology of cervical lesion. Two separate occlusal forces can create two occlusal line angles in cervical lesion. (From Lee & Eakle, 1984)*

The tensile force that acts on the tooth may cause disruption of chemical bonds between the hydroxyapatite crystals. The disrupted crystalline structure would be more susceptible to chemical dissolution and loss from physical forces such as friction from brushing, compression, and shearing during mastication and bruxism (Fig 43b). We have often detected this



In Figure 43b lateral forces create cervical tension and compression; magnification depicts disruption of chemical bonds between enamel rods. Crystals become more susceptible to breakage and dissolution. (From Lee & Eakle, 1984) phenomenon in stereomicroscopic pictures of cervical lesions. The enamel prisms become brittle (Fig 44a,b). Malocclusion and bruxism

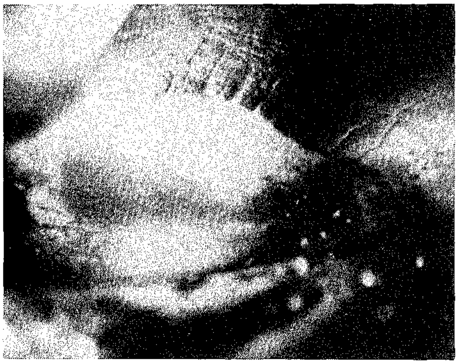


FIG 44(a,b). a: *Cervical lesion in region of tooth under tensile stress. Enamel cracks at the cervical enamel border.*

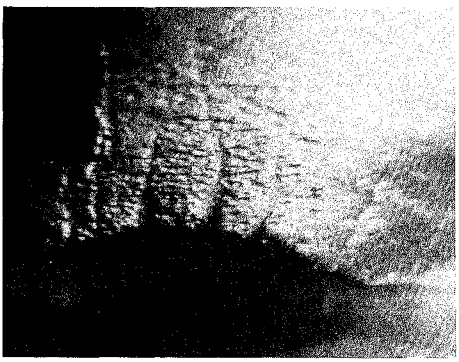


Figure 44b shows detail; disruption of the hydroxyapatite crystals.

are often found in combination with the cervical erosive lesions (Fig 45). For example, if there are two directions of lateral force acting

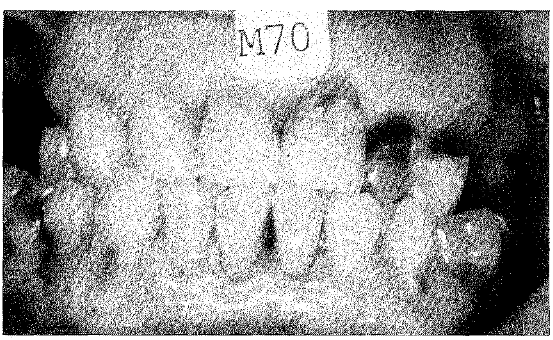


FIG 45. *Clinical view of large wedge-shaped cervical lesions in combination with malocclusion and bruxism*

on the same tooth, the lesions created would be two overlapping wedge-shaped volumes (Fig 46a,b).

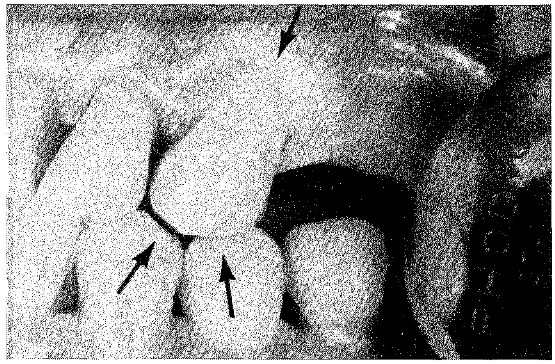


FIG 46(a,b). a: *Upper canine has two wear facets at the cusp in combination with a double cervical lesion.*

In Figure 46b, these facets show two distinct directions of occlusal forces acting on tooth that correspond to two distinct line angulations at occlusal edge of cervical lesion.

If such erosive lesions are restored with the acid-etch technique plus dentin adhesives, the occlusal factors must be taken into consideration, otherwise cervical debonding and leakage can result as the restoration is subjected to the same tensile forces. If the occlusion is not corrected, premature loss of the cervical restorations can be the result (Fig 47a,b). In some cases even the gradual progression of the cervical lesion around the restoration can be

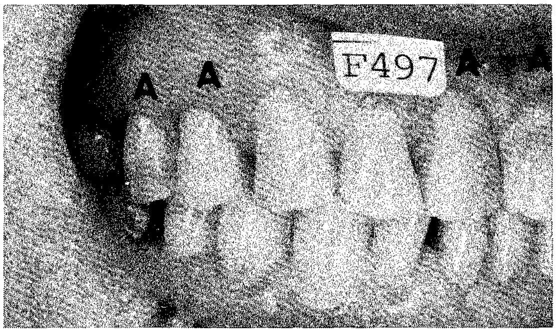


FIG 47(a,b). a: *Group A restorations immediately after filling procedures*

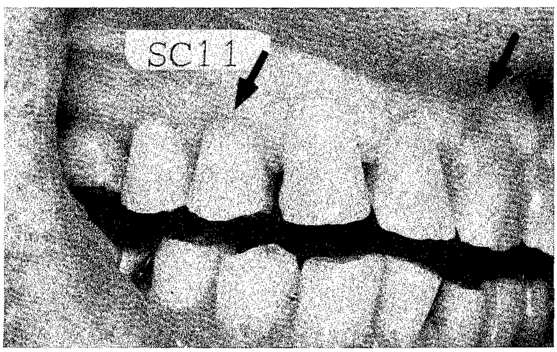


Figure 47b shows early loss of some restorations because of unnoticed occlusal overload.

explained in the same way. The disrupted tooth structure is more susceptible to loss through dissolution and abrasion and results in a lesion progression (Fig 48).

FIG 48. *Lesion progression around cervical restoration*

CONCLUSION

Dentin adhesives have many limitations. The durability of the bond created with dentin adhesive agents is adversely affected by several factors, such as: the low surface energy of the dentin itself, the hardness and smoothness of the lesion, the polymerization shrinkage of the resin, and the occlusal factors, all of which may play a part in the development of class 5 lesions. The dentist must be constantly aware of the limitations of these products in order to achieve the desired results.

Acknowledgments

The Buonocore Memorial Lecture is funded by the L D Caulk Company, Milford, Delaware.

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POINT OF VIEW

Posterior Composites: An Ethical Issue

JOHN A GILBERT

Summary

The use of posterior composite materials for class 2 restorations is rapidly increasing. Based on the scientific evidence presented thus far, such usage is not indicated. However, usage is on the increase, which presents many ethical questions for the profession. This article suggests a framework for ethical discussions of this type and concludes that the use of these materials is, in fact, unethical.

INTRODUCTION

Problems associated with the use of posterior composite materials are well documented (Leinfelder, McCartha & Wisniewski, 1985; Leinfelder, Wilder & Teixeira, 1986; Boksman, 1986). It is clear that they should only be used under limited conditions. There are no long-term studies to support their usage and several severe problems have arisen (Council on Dental Materials, 1986; Eick & Welch, 1986; Reinhardt & others, 1982). Yet, contrary to this scientific evidence, there is strong indication that posterior composites are being placed in large numbers (Vanherle & Smith, 1985). Some are being placed under the pseudoscientific guise of mercury-related problems and some for legitimate esthetic considerations (*Emphasis,* JADA, 1985). The fact is, however, that many perfectly good amalgam restorations are being replaced at the urging of the dentist and many dentists are using composite resins as their routine class 2 posterior restorative material. The reason seems clear — financial gain. The problem is so acute that the Michigan Dental Association passed a resolution condemning needless removal of amalgams (*ADA News,* 1986). The ethical problems in such practice are transparently clear, as an analysis, based on an ethics model, will show. The purpose of this paper is to evaluate the ethical use of posterior composites using the described ethics model.

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ETHICS

The American Dental Association has adopted and revised over the years the ADA Principles of Ethics and Code of Professional Conduct. Included in this code are the broad-based statements that govern our status as a profession and give the public assurance of our moral intent (Nash, 1984). This code, and others like it, both in medicine and dentistry, are based directly or indirectly on the Hippocratic Oath of ancient Greece. Such nonspecific codes or oaths are only general guidelines when specific ethical decisions are made by the practicing professional (Nash, 1984).

The dental profession has been viewed by the general public as among the most ethical of all professions (Cole, 1984). Although most ethical decisions in dentistry pale in comparison to the dramatic dilemmas of medicine, the profession does face many troubling ethical issues (Cole, 1984). Dentistry's ethical problems can best be analyzed within one of the popular frameworks used for ethical discussion in medicine (Gorovitz & others, 1983). This framework looks at ethical decision-making in terms of (1) autonomy, (2) beneficence and nonmaleficence, and (3) justice. Once an analysis has been made in this manner, the professional will be better equipped to make his or her ethical decisions.

Autonomy

Autonomy refers to the rights of the individual. Present western societies tend to place a great deal of emphasis on autonomy, frequently ranking it as the number one value when making ethical decisions. The individual ranks supreme and his autonomy must be respected above all. The strong movements toward informed consent and second opinions are reflections of the principle of autonomy. The paternalistic attitudes of medicine and dentistry, especially strong in the past, are directly opposed to autonomy (Gorovitz & others, 1983). Increasing numbers of patients no longer simply trust that the physician or dentist will do the "best" thing.

Beneficence

Beneficence (doing good) is the primary driving force of the health professions. We hope to make our patients better and eliminate disease. The cautionary corollary to beneficence is the principle of nonmaleficence (do no harm). We must always be aware that in our need to do good we do not actually harm our patients.

Justice

Justice discussions in an ethical framework usually relate to the utilitarian principle of doing the most good for the most people and frequently relate to the cost of a service or treatment versus the benefit to society as a whole. In this day of high technology, discussions of justice are coming more to the front of ethical analysis. Just because we *can* do a treatment or technique does not mean we *must* or *should* provide this service. For example, the artificial heart is at the center of many recent justice discussions.

THE ISSUE: POSTERIOR COMPOSITES

Today the individual dentist is faced with major ethical decisions regarding new materials and techniques being promoted to the profession. The use of posterior composites is an example of a type of material that presents serious ethical problems for the dentist and the dental profession.

Autonomy in Practice

To offer true autonomy for patients before posterior composites are placed, complete information on the advantages and disadvantages of these materials must be provided and explained to the patient. The official position of the ADA should be part of this information and only information based on sound scientific studies should be provided (Council on Dental Materials, 1986). The patient should have the opportunity to ask questions and the answers should be both clear and unbiased. The patient should understand the various choices of materials available and be allowed to make his or her own decision. It is doubtful that many patients would choose posterior restorations of composite if this information were provided.

Beneficence in Practice

The dentist's desire and oath to be beneficent and to observe the principle of nonmaleficence must enter into the decision to place posterior composites. Based on the present state of the art, only if esthetic concerns are the overriding value would the use of these materials be justified. There is no evidence that the placement of posterior composites could be considered "doing good," while there is substantial evidence that the dental health of the patient can be harmed by the placement of these materials. This is especially true if sound amalgam restorations are removed and replaced with the composites.

Justice in Practice

In terms of justice there can be little to defend the placement of the posterior composite materials. The technique for placement is more difficult, more time consuming, and the material is more expensive than amalgam. Therefore, the restorations must be higher in cost than those of amalgam. Even if the posterior composite materials were equal in mechanical properties to amalgam, the additional cost would be difficult to justify. Only if and when these materials are clearly superior to amalgam would there be justice in their placement. It is obvious that, in terms of justice, there cannot be an argument made to replace a sound amalgam restoration with composite. If the principles of justice are violated by placing posterior composites as a new restoration, they are most certainly violated when this material is used to replace serviceable amalgams. The funds expended in such a manner must be used to promote health in a different and in the most just way.

CONCLUSIONS

Thus, an examination of the value of placement of posterior composites, using an ethical model, can only lead to one conclusion — the use of these materials is seldom justified. When examined from the perspective of autonomy, beneficence/nonmaleficence, and justice, the use of these materials in many cases actually becomes unethical. Rationales for their use cannot stand up to such an analysis.

The above ethical discussion is not meant to replace a scientific analysis of a technique or material. It is only hoped that such an ethical analysis, along with the scientific facts, will help the individual dentist make an informed and ethical decision when new materials or techniques are advanced. As new scientific studies are released concerning a material or technique, the same ethical model can be helpful in the decision-making process. The final analysis and conclusions may differ but the basis of the discussion remains the same, thus helping insure that thoughtful ethical decisions are made by the professional.

(Received 2 December 1986)

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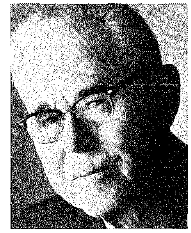

Hollenback Prize for 1987

The Hollenback Memorial prize for 1987 has been awarded to Gunnar Ryge, who recently retired as assistant dean for research at the School of Dentistry, University of the Pacific, in San Francisco. This award is given annually by the Academy of Operative Dentistry to recognize excellence in research and dedication to the advancement of operative dentistry.

The research of Dr George Hollenback can be characterized as oriented in materials, investigative in nature, fundamental in concept, and clinical in application. This award, given in Dr Hollenback's memory, goes to a man who has fulfilled each of these attributes in his own illustrious career. We look back to Dr Hollenback for improved materials with which we have worked, for pioneering techniques which we have practiced, and for innovative instrumentation which has increased our capability. Today, we recognize Dr Ryge for his basic research in metals which has led to the development of improved casting alloys, for his technical assistance in the improvement of casting technics, and for a clinical evaluation instrument that has initiated an entirely new area of applied research.

Dr Ryge began his studies at the University of Copenhagen and obtained his dental degree from the Royal Danish Dental School in 1939. After graduation he engaged in the practice of dentistry in both Copenhagen and Struer, Denmark. At the same time he also began a teaching career at the Royal Danish Dental School, where he rose from the rank of instructor to associate professor in the Departments of Dental Materials and Operative Dentistry. In 1949, Dr Ryge came to the United States as a guest researcher at the National Bureau of Standards in Washington, DC. A year later he enrolled in the graduate school of Marquette University in Milwaukee, Wisconsin, where he received a master of science degree in physics and mathematics. His teaching career was renewed at Marquette University Dental School, where he again started as an instructor and progressed to the rank of professor in Dental Materials Science. He was also department chairman for most of his 14 years at Marquette University. During his tenure there, Dr Ryge engaged primarily in researching metallurgy, evaluating casting alloys, and studying new gypsum investments and casting technology.

In 1964, Dr Ryge took a leave from his academic appointments and became chief in the Materials and Technology Branch, Division of Dental Health, at the National Institutes of

Health. In 1969, he became the director of the Dental Health Center in San Francisco. It was in this capacity that he made his greatest contribution to the field of dentistry by developing written criteria for the evaluation of dental restorations and attempting to standardize their application. Although primarily created to rate the serviceability of amalgam and composite resin restorations and to determine agreement on the "decision to replace," these criteria soon became an invaluable instrument in clinical research. Through his pioneering work at the Center, we have come to understand these terms: independent evaluator, judgment call, consensus decision, interexaminer and intraexaminer agreement, and clinical calibration. Although still the standard in the field, his criteria and rating scales have been modified many times to gain greater discrimination in research and have been adapted to include a wider variety of materials. Under his keen eye and quick judgment, many of us in the academic community have undergone training sessions and learned the true science of clinical evaluation.

In 1972, Dr Ryge returned to the university setting as assistant dean for research at the School of Dentistry of the University of the Pacific in San Francisco. There he actively pursued independent clinical research projects, initiated multisupport programs, and consulted in both the academic and industrial environment. He has served as a national consultant to the American Dental Association (Councils on Dental Research and Dental Materials and Devices), the Veterans Administration Hospitals, and the National Institutes of Health. He has had an active role in the development of both national and international standards for dental materials. He has held offices in the Federation Dentaire Internationale, the American Association for the Advancement of Science, the American College of Dentists, and the American Public Health Association. His honors include membership in Omicron Kappa Upsilon (dental honor society), Sigma Pi Sigma (physics honor society), and Sigma Xi (science honor society). He received the Wilmer Souder Award from the Dental Materials Group, IADR, in 1966, and was elected president of the International Association for Dental Research in 1972-73. He also received the honorary degree of Doctor of Odontology from the University of Lund, Mälmo, Sweden, in 1980. His current title is professor emeritus, School of Dentistry, University of the Pacific.

Gunnar Ryge

It would be unfair to conclude this brief summary of Dr Ryge's professional life and contributions to dentistry without a special application of his rating scale. ALPHA, the first letter of the alphabet, indicates the pioneering spirit and courage that he has displayed in adapting scientific methodology to clinical evaluation. BRAVO, a term that describes a shout for accomplishment, is a most appropriate rating for his success in establishing quality consciousness and stimulating self-evaluation in clinical practice. CHARLIE, a folksy term that symbolizes the man next door, depicts for us the unselfish attitude that he has displayed in continually sharing his knowledge and experience with all of us.

It is with deep respect, love, and admiration that the Academy of Operative Dentistry honors Dr Gunnar Ryge with the Hollenback Award for 1987.

JOSEPH B DENNISON

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Award of Excellence

The award of excellence of the Academy of Operative Dentistry is presented annually in recognition of service to the Academy, the teaching of operative dentistry, the promotion of good dentistry on both the national and international levels, and most importantly, for excellence in dentistry. This year's recipient is Dr Paul T Dawson.

It is an honor for me to have the opportunity of sharing with you a few of the many accomplishments of this great human being which has justified his selection for this most prestigious award. Dr Dawson entered Loyola's dental school in 1924 and began his teaching career there in 1929 as an instructor in physiology. During his early academic career, which ultimately spanned 54 years, he also taught diagnosis, crown and bridge, radiology, orthodontics, therapeutics, endodontics, pedodontics, and operative dentistry.

From 1951 to 1967 Dr Dawson was professor and chairman of the Department of Operative Dentistry and established himself as a preeminent educator in his field. Following his "retirement" from Loyola in August 1970 he joined the faculty of the operative department at Northwestern University in September 1970 and spent the next 13 years working every day teaching restorative procedures and engendering that enthusiasm for quality dental service that can only be provided by a man of his talent and high ideals.

On the occasion of his retirement from Northwestern I cited the following quotation: "A good teacher affects eternity for he can never tell where his influence stops." In a very real sense, Paul Dawson is a teacher who teaches dentistry. He is simply **not** a dentist who teaches.

It is said that to be a good teacher one must have a knowledge of his subject and a desire to impart it. There is no question of Paul's depth of knowledge or his love of dentistry. It is the teacher in him, however, that has caused him to be recognized and loved by anyone who

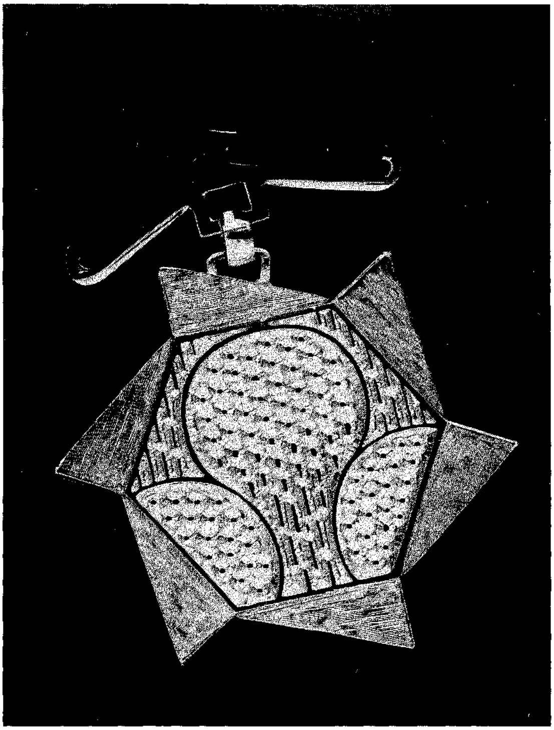
Paul T Dawson

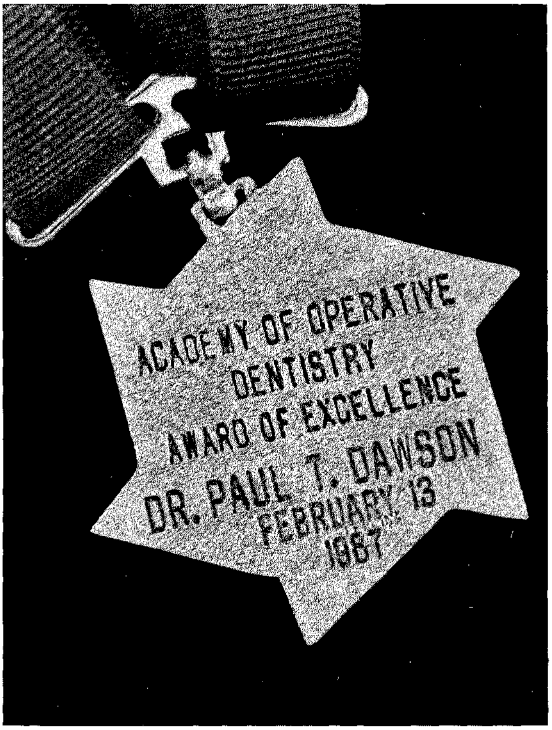
walks in his shadow. And today it is Paul Dawson that we are honoring — not the dentist in him, but the colorful, cheerful, humble, caring, loving person that he is and that has caused him to become a legend in his own time.

Phillip Brooks, a great spiritual leader of the last century, said: "No man or woman of the humblest sort can be really strong, gentle, pure, and good, without the world being a better place for it, without somebody being helped and comforted by the very existence of that goodness." Today there are thousands of dentists throughout the world who are rendering a better dental service in a more professional manner as a direct result of the influence of Dr Dawson.

Throughout his career, Paul has been the recipient of awards and honors from Loyola, his first alma mater, from Northwestern, his second alma mater, and from the many professional

The medallion, hung on a black background; back view on left





organizations and societies to which he gave so freely of his time and talent. In 1981, he received an award that eclipsed all of the others. In that year he received the Distinguished Service Award of the American Dental Association. This is the highest honor that the ADA can give to a member of the dental profession.

Paul and his wife of nearly 56 years, Charlotte, still live on the family farm in Clark County, Illinois, where Paul was born, as were their three children Joy, Bessie, and Bill. Sir James Barrie said: "Every man who is high up loves to think he has done it all himself; and the wife smiles, and lets it go at that." Such it is and has always been with Charlotte!

In summary, then, we are paying tribute to Paul Dawson today because throughout his life he has always been a professional gentleman. Harry Lyons, former dean of the Medical College of Virginia, when defining a professional gentleman, once said in part: "...He professes his dedication to the public's welfare over his own. He professes that he gives more than he receives, willingly, and by design. He professes his indebtedness to his predecessors from whom he inherited the knowledge, the skills and the tradition of his profession. He professes that he, in turn, will enrich and further endow the profession in which he enjoys membership."

Paul Dawson, you **are** such a gentleman, and all of us in this room have been enriched by your membership in and contributions to our great dental profession. Congratulations!

CLIFFORD H MILLER, DDS

DEPARTMENTS

Announcements

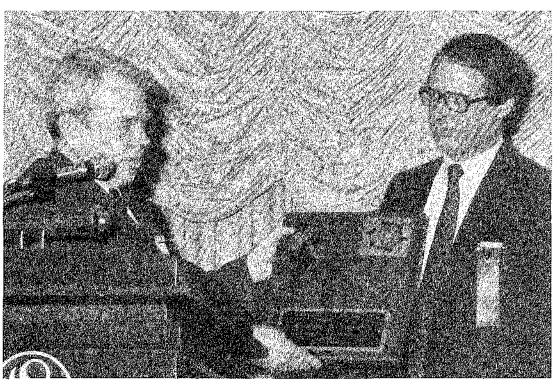
NEWS OF THE ACADEMIES

Academy of Operative Dentistry

The sixteenth annual meeting of the Academy of Operative Dentistry was held 12 and 13 February in Chicago at the Westin Hotel. An excellent program of essays, table clinics, and limited attendance clinics was presented. The sixth M G Buonocore Memorial Lecture was delivered by Paul Lambrechts.

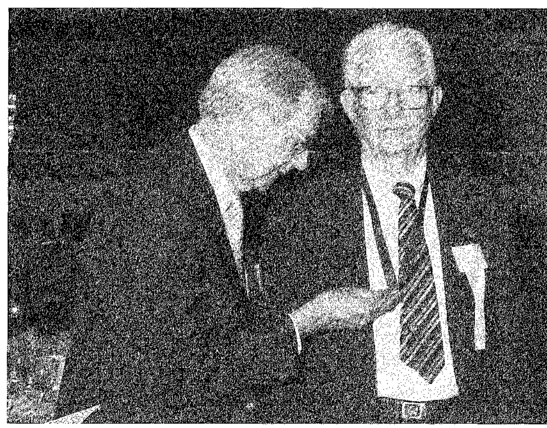
At lunch on the first day the Hollenback Memorial Prize was presented to Gunnar Ryge and the Student Achievement Award to Todd M Walker of the University of Iowa. Paul T Dawson was presented the second Award of Excellence at the luncheon on the second day.

Officers elected for 1987 are: president, William N von der Lehr; immediate past-president, Frank K Eggleston; president-elect, J Martin Anderson; vice-president, Anna T Hampel; secretary-treasurer, Ralph J Werner; assistant secretary, Gregory E Smith; and councillors, Baxter B Sapp, Judson Klooster, Robert D Cowan, Ralph M Phelan, Daniel C T Macintosh, and Charles F Morris.



New president William von der Lehr presents immediate past president Frank Eggleston a plaque in appreciation for his service.

Paul Lambrechts is introduced to the audience by Joseph Dennison.



Ralph Phillips examines the medallion for the Award of Excellence awarded to Paul Dawson.

NOTICE OF MEETINGS

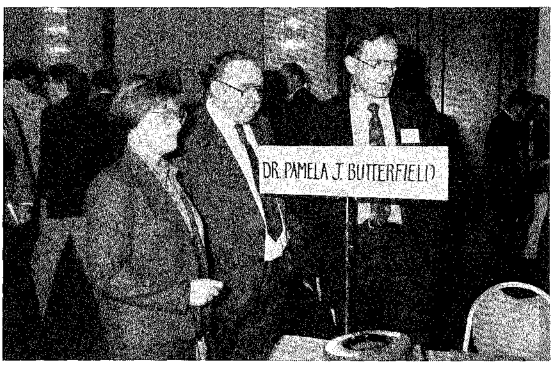
Academy of Operative Dentistry

Annual Meeting: 18 - 19 February 1988
Westin Hotel
Chicago, Illinois

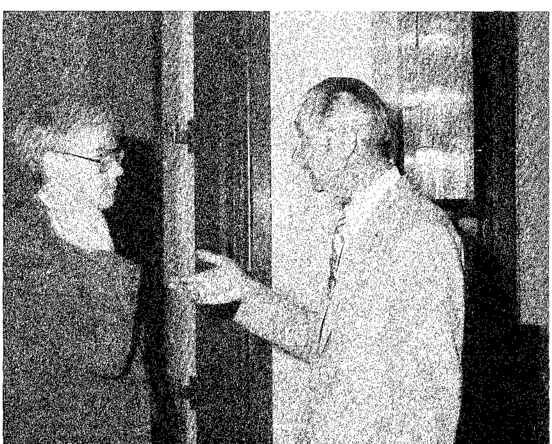
American Academy of Gold Foil Operators

Annual Meeting: 8 - 9 October 1987
University of Colorado
Denver, Colorado

Gunnar Ryge is congratulated on the Hollenback Award by Frank Eggleston.



Pamela Butterfield presents her table clinic on direct filling golds.



James Vernetti tells Ron Harris how it really *goes.*

Student Achievement Award

The winner of the Outstanding Student Achievement Award for 1987 is Todd M Walker, currently a junior dental student at the University of Iowa. Todd received a bachelor of arts degree from Valparaiso University in Indiana, where he majored in chemistry. As a first-year dental student, Todd developed his first table clinic, titled "Adhesive bases for posterior composite restorations," which was displayed at the dental school competition (second place) and at the annual session of the Iowa State Dental Association. He received a student research training grant for the summer of 1985 to study "Acid penetration through glass ionomer bases" and presented his work at the American Association for Dental Research meeting in Washington, DC, last spring. In 1986 he received a second fellowship to evaluate "The pulpal response to potassium oxalate," and a paper on this project will be presented at the IADR meeting in Chicago in March. His second table clinic venture placed first in the dental school competition and was presented at the Wisconsin Dental Association Annual Session and at the ADA student presentations in Miami.

Todd presented his table clinic "Innovations in Adhesions" for the Academy members. He is to be congratulated on these significant accomplishments.

Todd Walker receives the plaque for the Outstanding Student Achievement Award from Joseph Dennison.

Annual Meeting of the ABOD

Four newly certified members were received into membership of the American Board of Operative Dentistry at its annual meeting February 11, held in conjunction with the Academy of Operative Dentistry in Chicago. They are: Dr (Lt Commander, USN) Gordon K Jones (Lake Forest, IL), Dr (Captain, USN) Ronald C House (Bethesda, MD), J Craig Passon (Denver, CO) and Daniel T Snyder (Ann Arbor, MI). They were presented a Certificate of Proficiency in Operative Dentistry at a luncheon hosted by the Board. This distinction was earned by the recipients after having completed all three phases of the examination over a period of two or more years.

The officers for the ABOD are: president, William T Pike; vice-president, John W Reinhardt; secretary-treasurer, James V Gourley; councillors, Charles B Cartwright, Donald H Downs, Daniel Frederickson, Ralph L Lambert, Jose E Medina, and Julian J Thomas, Jr.

New certified members, left to right: Ronald C House, Gordon K Jones, J Craig Passon, and Daniel T Snyder

Audiovisual Listings Available

For the past two years, the Study Club Committee of the Academy of Operative Dentistry has been soliciting input from educational institutions concerning the availability of audiovisual teaching materials which could be made available to members of the Academy and study clubs. The response has been very favorable. The Academy wishes to thank all those institutions which have agreed to participate.

Due to the voluminous nature of the material acquired, it was felt that an item-by-item listing would be very repetitious and expensive to produce. Instead, the Executive Council of the Academy has directed the committee to make available a list of those institutions which have responded, and allow individuals and study clubs to pursue further correspondence on their own.

The listing is now available to Academy members by writing to Dr Richard Buchanan, 7921 Triple Crown, Boerne, TX 78006. Please enclose $2.00 to cover duplication, postage, and handling. Make all checks payable to the Academy of Operative Dentistry.

Certification Program in Operative Dentistry

The Operative Dentistry Certification Program is a three-part examination designed and administered by the American Board of Operative Dentistry, Inc (ABOD). This program was developed with the support and sponsorship of the Academy of Operative Dentistry.

Candidates must successfully complete written, oral, and clinical examinations in order to attain the Certificate of Proficiency in Operative Dentistry. The written examination covers a broad spectrum of areas related to the diagnosis and treatment of oral disease. After successful completion of the written examination, a candidate submits documented cases of completed restorative treatment. Those cases serve as the basis for the oral examination and require patient treatment, including cast and compacted gold, amalgam, and porcelain restoration.

The examinations are regularly scheduled for the convenience of the candidates. The written examination will be given in September 1987 if sufficient candidates are available and again at its regular time, February 1988. The oral and clinical examination is scheduled for late August or early September 1987 in Seattle, Washington. An East Coast site is proposed for the 1988 oral and clinical examination.

All correspondence related to applications, dates, sites, and time of examinations, as well as general inquiries and completed applications, should be addressed to:

Dr James V Gourley
Secretary-Treasurer
12238 Olympic View Road
Silverdale, WA 98383

INSTRUCTIONS TO CONTRIBUTORS

Correspondence

Send manuscripts and correspondence about manuscripts to the Editor, David J Bales, at the editorial office: OPERATIVE DENTISTRY, University of Washington, School of Dentistry SM-57, Seattle, WA 98195, USA.

Exclusive Publication

It is assumed that all material submitted for publication is submitted exclusively to *Operative Dentistry.*

Manuscripts

Submit the original manuscript and one copy; authors should keep another copy for reference. Type double spaced, including references, and leave margins of at least 3 cm (one inch). Supply a short title for running headlines. Spelling should conform to *Webster's Third New International Dictionary,* unabridged edition, 1971. Nomenclature used in descriptive human anatomy should conform to *Nomina Anatomica,* 5th ed, 1983; the terms 'canine', 'premolar', and 'facial' are preferred but 'cuspid', 'bicuspid', and 'labial' and 'buccal' are acceptable. SI (Système International) units are preferred for scientific measurement but traditional units are acceptable. Proprietary names of equipment, instruments, and materials should be followed in parentheses by the name and address of the source or manufacturer. The editor reserves the right to make literary corrections.

Tables

Submit two copies of tables typed on sheets separate from the text. Number the tables with arabic numerals.

Illustrations

Submit two copies of each illustration. Line drawings should be in india ink or its equivalent on heavy white paper, card, or tracing vellum; any labeling should be on an extra copy or on an overleaf of tracing paper securely attached to the illustration, not on the illustration itself. Type legends on separate sheets. Photographs should be on glossy paper and should be cropped to remove redundant areas. For best reproduction a print should be one-third larger than its reproduced size. Maximum size of figure is 15x20 cm (6 x 8 inches). The cost of color plates must be met in full by the author. On the back of each illustration, near the edge, indicate lightly in pencil the top, the author's name, and the number of the figure. Type legends on a separate sheet. Where relevant, state staining techniques and the magnification of prints. Obtain written consent from holders of copyright to republish any illustrations published elsewhere.

References

Arrange references in alphabetical order of the authors' names at the end of the article, the date being placed in parentheses immediately after the author's name. Do not abbreviate titles of journals; write them out in full. Give full subject titles and first and last pages. In the text cite references by giving the author, and, in parentheses, the date, thus: Smith (1975) found . . .; or, by placing both name and date in parentheses, thus: It was found . . . (Smith & Brown, 1975; Jones, 1974). When an article cited has three authors, include the names of all of the authors the first time the article is cited; subsequently use the form (Brown & others, 1975). Four or more authors should always be cited thus: (Jones & others, 1975). If reference is made to more than one article by the same author and published in the same year, the articles should be identified by a letter (a, b) following the date, both in the text and in the list of references. Titles of books should be followed by the name of the place of publication and the name of the publisher.

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OPERATIVE DENTISTRY

SPRING 1987 • VOLUME 12 • NUMBER 2 • 41–88

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