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EDITORIAL

Hillary Rodham Clinton, Chairperson
National Task Force for Health Care Reform
White House, Washington, DC 20500

Dear Ms Clinton:

I am writing you in strong support of inclusion of basic dental health care as part of the national health care reform package being developed by the National Task Force for Health Care Reform.

As the person charged with organizing a compassionate and effective response to one of the great problems faced by our society, you know that this is a complex of interrelated issues. The barriers to health, education, and economic growth for segments of our society are increasingly interrelated. Progress in any area can lead to significant improvements in other areas. The past four years of debate on health system reform have focused almost exclusively on problems of cost and access to physician care, hospital services, and pharmaceuticals. Because of the lack of consideration of dental needs, a significant number of policymakers have come to believe that dental issues are of minimal concern. Yet dental diseases are the most common health problem faced by our society. Conversely, prevention of dental disease and a basic dental care package for selected populations offers your committee one of the best returns on investments available in the health care market.

As a group of health care professionals, the dental community has worked effectively to reduce dental diseases in our population. The 1987-88 NIH study showed that about 50% of the children in the United States were caries free. However, the same study shows that 20% of our population have 60% of the dental caries. The differences in the incidence and prevalence of dental caries are most strikingly defined by socioeconomic status. The economically disadvantaged members of our society suffer a disproportionate share of dental diseases. Dental disease is the number one health problem for preschool children in Head Start and Early Childhood Education and Assistance Programs in my state. Each year 117,000 school hours are lost due to dental disease per 100,000 children across our country. Dental pain creates learning problems for school-age children. Disfigurement caused by dental diseases and trauma can lead to long-term problems with self-esteem in children and adults. These and other dental-related factors compound the problems of upward socioeconomic migration within our society. Our adult work force loses 148,000 work hours per year per 100,000 individuals due to dental disease.

An emerging group that needs our focus is the growing geriatric population. The dental needs of this group are increasingly complex. More and more of our senior citizens are retaining their teeth. Medications prescribed for other health-related problems alter basic oral functions. This leads to almost immediate problems with taste, root caries, and periodontal diseases. Prevention of dental disease in this group is important to the healthful longevity of these citizens and has a direct impact on their quality of life. The existing Medicare program should be expanded to include coverage for additional dental health care services critical to this group.

With proper care, dental diseases are almost totally preventable. However, 33% of our population do not, or cannot, seek preventive services or basic dental care. Over 100 million Americans do not have access to fluoridated water, the single most effective preventive public health measure in history.

Any health care reform package must stress prevention and include dental funding for prevention, early intervention, and emergency programs for underserved children and adults. At a minimum, your committee should mandate preventive health programs that support oral health screening examinations, dental sealants for all children, oral prophylaxis, topical fluorides, and a basic dental services plan for restorative and periodontal therapy. In dentistry, as in medicine, prevention is far more cost-effective than repairing the damage caused by diseases.

The dental benefits programs of the Uniformed Services Dependent Dental Care program can be used as an economic model. There are sufficient data now available to predict the cost of various levels of care. This program has specified benefits and broad provider participation. It is administered by a private-sector carrier on a competitive bid contract. While not a perfect program, it does meet many of the needs of its beneficiaries.

Finally, I want to wish you and your committee the best in your endeavors. I wish you the wisdom, insight, and courage to bring our citizenry's dental health into the mainstream of total health care.

MH ANDERSON
Editor

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ORIGINAL ARTICLES

Restoration Deterioration Related to Later Failure

ROGER J SMALES • DAVID A WEBSTER

Clinical Relevance
Replacement of restorations based on traditional signs thought to be associated with impending failure seems unnecessary.

SUMMARY

The purpose of this study was to determine the relationship between the deterioration and the later failure of a very large number of amalgams and anterior resin composites examined over periods of up to 16 years. Assessments were made of the deterioration of various clinical factors or characteristics of the restorative materials that were thought to predict later failures. True failures, which were directly related to the restorative materials, accounted for 7.5% of the amalgam and 30.4% of the composite restorations. For the amalgams, there was a significant association found between the failures and surface tarnishing. Marginal fracture and marginal staining were not associated significantly with any of the three different failure modes. For the composites there were significant associations found between the failures and surface roughness, marginal fracture, and color mismatch. Surface staining and marginal staining were not associated significantly with any of the three different failure modes. Many restorations assessed as being unsatisfactory continued to function for a further 2.5 to 3.5 years on average before being replaced, often for unrelated reasons. There is a need to define unsatisfactory restorations more clearly in terms of actual adverse effects on dental health, rather than merely in terms of restoration deterioration.

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INTRODUCTION

It has been stated that "In trying to determine the long-term durability of amalgam restorations a major problem is how the short-term clinical behavior of the restorations can be used to predict the long-term durability" and "When a clinical characteristic shows a change or initial progress in change during the functioning of the restoration, it may be of value for a determination of the long-term durability" (Letzel, 1975). It has also been stated that "Progress towards determining the composition and construction of the ideal restorative system may have been, to a certain extent, hampered by a preoccupation with investigations of changes in the functional characteristics of restorations in clinical service rather than with research capable of determining predictors and modes of clinical failure. Consequently, material scientists still largely lack clear, clinically derived guidelines to assist them in their quest for the ideal restorative system" (Wilson, 1989).

Although a number of apparently relevant deterioration factors or breakdown characteristics of restorations have now been evaluated in many clinical trials, there is scant evidence relating restoration deterioration behavior to their later replacement modes. Even the relationship of marginal fracture to predictions of amalgam restoration failure is still uncertain (Smales, 1991). Reports of a long-term study of 19 posterior composite resins also found that, despite some initial differences, all appeared to decrease in their wear rates to eventually approach the same overall wear level (Roberson & others, 1988), accounting for negligible failures (Bayne & others, 1989).

During the collection of data for previous long-term studies, it was also noticed that many restorations judged to be clinically unsatisfactory for deterioration often continued to function adequately for several more years before being replaced, often for quite different and unrelated reasons. In contrast to this observation, other restorations judged to be satisfactory were sometimes replaced soon after such assessments were made.

Therefore, the present long-term study examined the clinical behavior of a large number of amalgam and anterior composites to evaluate the relationship between their deterioration in quality and the reasons for their later failures.

METHODS AND MATERIALS

Information was obtained from several clinical studies of five amalgam alloys and four anterior resin composites that had been placed in the permanent teeth of 400 and 500 patients respectively by a large number of students and staff at a dental hospital.

Briefly, the 2225 amalgam restorations were assessed directly, and indirectly by supplemental color photography, for surface roughness and tarnishing, and marginal staining and fracture, using an ordinal rating scale where 0 represented no detection of any deterioration (Good), 1 represented slight or obvious changes from ideal or excellent (Adequate), and 2 represented severe changes requiring operative intervention (Unsatisfactory). The 1871 anterior resin composite restorations were assessed for surface roughness and staining, marginal staining and fracture, and color mismatch, using ratings of 0 (Good), 1 slight and 2 obvious changes (Adequate), and 3 severe changes (Unsatisfactory). Details of the rating scales and assessment methods used have been published (Smales, 1977, 1983).

True restoration failures included restoration replacements and repairs, losses and fractures, and marginal caries. Apparent restoration failures caused by unrelated factors such as extractions, endodontic access, trauma, tooth fracture, or by incidental incorporation into other restorations were treated as censored values in the analyses.

The deterioration behavior of those restorations that failed over periods of up to 16 years was compared with those that did not fail, but remained intact. Because of the ordinal nature of the rating scales, the scores for the different clinical factors at each observation were first transposed to Z-values. The method involved ordering all the original rating scores by rank, calculating the empirical probability of each score from the data, and then selecting the Z-value from the normal Gaussian distribution curve with the same probability. A Cox proportional hazards model survival analysis was then performed on the time to failure, using a number of clinical factors such as surface roughness, color mismatch, etc, as time-varying covariates. The value of each covariate was calculated from the observed scores measured over the lifetime of each restoration by using numerical integration techniques. By definition, this made each covariate time varying, and hence the appropriate model and method of analysis preferred was that used in program 2L, BMDP Statistical Software (Dixon, 1990). Thus, this analysis enabled the relationship between observable signs of deterioration and the failure time of each restoration to be examined.

Life table evaluations were also made of the cumulative survivals of amalgam and composite restorations following the first recordings made of unsatisfactory ratings for the various clinical factors assessed, using BMDP program 1L. Differences between the mean scores over the study were assumed to be present at a statistically significant level of 0.01 or less.

RESULTS

Because many of the restorations were examined on more than one occasion in longitudinal clinical trials, there were 4129 amalgam and 3116 composite restoration observations recorded over the study. True failures accounted for 7.5% of the amalgam and 30.4% of the composite restorations. For apparent failures, the percentages were 2.5 and 3.7 respectively. The numbers of restorations rated as being unsatisfactory for each clinical factor are shown in Table 1. The main effects of the deterioration behavior of the amalgam and composite restorations when related to their later survival or failure are shown in Tables 2 and 3.

For the amalgam restorations, there was a significant association found between the

Table 1. Number of Restorations Rated as Being Unsatisfactory for Each Clinical Factor Assessed

Restorations (Totals)	Surface Roughness	Surface Tarnish/Stain	Marginal Stain	Marginal Fracture	Color Mismatch
Amalgams (2225)	6.3% 140	9.8% 219	2.6% 58	7.8% 173	
Composites (1871)	1.3% 24	2.3% 43	4.1% 77	2.6% 48	8.0% 150

Table 2. Amalgam Restoration Deterioration Related to Later Survival or Failure

Failure Modes (N)*	Surface Roughness	Surface Tarnish	Marginal Stain	Marginal Fracture
All failures (167)	0.928	<0.001**	0.369	0.684
Replaced or repaired (91)	0.768	<0.001**	0.438	0.791
Lost or fractured (55)	0.122	<0.001**	0.257	0.389
Marginal caries (21)	<0.001**	0.266	0.484	0.355

*Number of failed restorations
**Significant association present at the 1% probability level

Table 3. Resin Composite Restoration Deterioration Related to Later Survival or Failure

Failure Modes (N)*	Surface Roughness	Surface Stain	Marginal Stain	Marginal Fracture	Color Mismatch
All failures (568)	<0.001**	0.019	0.260	<0.001**	0.001**
Replaced or repaired (91)	0.385	0.030	0.701	0.007**	0.012
Lost or fractured (424)	<0.001**	0.727	0.587	0.001**	0.004**
Marginal caries (53)	0.023	0.012	0.836	0.004**	0.773

*Number of failed restorations
**Significant association present at the 1% probability level

failures and surface tarnishing. When the assessments were analyzed further into three different failure modes, there were significant associations found between replaced or repaired restorations and surface tarnishing, between lost or fractured restorations and surface tarnishing, and between marginal caries and surface roughness ($P < 0.001$). Marginal fracture and marginal staining were not associated significantly with any of the three failure modes (Table 2).

For the composite restorations, there were significant associations found between the failures and surface roughness, marginal fracture, and color mismatch. When the assessments were analyzed further into three different failure modes, there were significant associations found between replaced or repaired restorations and marginal fracture; between lost or fractured restorations and surface roughness, marginal fracture, and color mismatch; and between marginal caries and marginal fracture ($P < 0.01$). Surface staining and marginal staining were not associated significantly with any of the three failure modes (Table 3).

The times taken for the amalgam and composite restorations to fail once they had been assessed as being unsatisfactory for a clinical factor are shown in Table 4. The times were as long as 11 years for marginal fracture of both types of materials and 13 years for color mismatch of the composites. However, for both types of materials, the median survival times were around a further 2.5 to 3.5 years for any clinical factor, once it had been assessed as being unsatisfactory. The numbers of restoration failures associated with the different unsatisfactory clinical factors were relatively low, especially for the amalgams.

DISCUSSION

Restoration Deterioration

In the present study, the most frequent reasons for unsatisfactory deterioration assessments were surface tarnish (9.8%) for amalgams and color mismatch (8%) for composites (Table 1). Around 20% of amalgam and 15% of composite restorations were assessed as being unsatisfactory. A comprehensive review of many earlier studies, mainly surveys, found that approximately one-third of all restorations present may be unsatisfactory, usually because of poor contours and margins and inadequate extension and retention (Elderton, 1976). More recent surveys of the quality of existing restorations have recorded 10 - 26% as being unsatisfactory, with the main problems being related to

Table 4. Abbreviated Life Table Survival Results over Periods of up to 4-13 Years for Amalgam and Composite Restorations, following Unsatisfactory Rating Assessments

Clinical Factors (N)*	Number of Failures	Cumulative Survival ±SEr**%	Median Survival ±SEr**years
Amalgams			
Surface roughness (140)	9	21 ± 13 (9 years)***	2.8 ± 0.6
Surface tarnish (218)	10	28 ± 14 (10 years)	3.8 ± 0.6
Marginal stain (58)	4	50 ± 18 (9 years)	3.6 ± 0.2
Marginal fracture (173)	23	0 ± 0 (11 years)	3.4 ± 0.3
Resin Composites			
Surface roughness (24)	9	0 ± 0 (4 years)	2.3 ± 0.3
Surface stain (43)	10	10 ± 9 (5 years)	3.6 ± 0.6
Marginal stain (77)	29	0 ± 0 (10 years)	3.2 ± 0.5
Marginal fracture (48)	19	10 ± 7 (11 years)	2.2 ± 0.3
Color mismatch (150)	38	3 ± 3 (13 years)	2.2 ± 0.3

*Number of restorations assessed as unsatisfactory, **Standard Error, ***Period in years at which the last observations were made poor contour, caries and poor margins, and bulk fracture for amalgams, and to color mismatch and marginal staining for anterior composite resins (Rytömaa & others, 1984; Allander, Birkhed & Bratthall, 1989; Kroeze & others, 1990).

Restoration Failure

Many of the low numbers of amalgam restoration failures were designated as replacement or repairs, and would have included a number of restorations failing because of unsatisfactory ratings for the clinical factors examined, as well as from other unknown reasons. Most of the higher numbers of composite restoration failures were from losses (lack of retention) and bulk fractures. The treatment of apparent failures as censored values in the analyses avoided ascribing unrelated factors to the deterioration behavior of the restorative materials.

It was often not possible to determine the exact cause(s) of failure from the patient records of treatments and, as the classification of restoration failure also differs between various studies, it is not possible to compare the studies with a high degree of confidence. However, median survivals for amalgam restorations in studies other than clinical trials have been reported as being around seven to 11 years, with failures mainly from caries, bulk fractures and losses, marginal fractures, and tooth fractures (Allander, Birkhed & Bratthall, 1990; Qvist, Qvist & Mjör, 1990a; Cheetham, Makinson & Dawson, 1991; Jokstad & Mjör, 1991). For anterior composites, comparable study findings have shown median survivals around five to seven years with failures mainly from caries, bulk fractures and losses, marginal fractures and staining, and color mismatches (Smales, 1977, 1991; Mjör, 1981; Qvist, Qvist & Mjör, 1990b).

Restoration Deterioration and Failure

The assumption from many clinical trials, especially those assessing occlusal marginal fracture of amalgams and the occlusal wear of posterior composite resins, is that early detection of differences in restoration deterioration between materials may be used reliably to predict differences between the materials in their later failures. However, the most common and very low failure modes reported for amalgam restorations in clinical trials have been bulk fracture, followed by caries and tooth fracture. Marginal fracture, per se, has been a minor reason for failures over periods of up to 19 years (Akerboom, Advokaat & Borgmeijer, 1986; Letzel & others, 1989; Moffa, 1989a; Jokstad & Mjör, 1991). Even in cross-sectional surveys, marginal fracture has usually accounted for only around 5 - 20% of all amalgam restoration failures (Cheetham & others, 1991; Smales & others, 1991). Similarly, the most common and fairly low failure modes reported for posterior composite restorations in clinical trials have been caries and bulk fracture, followed by occlusal wear and pulpal problems. Wear, per se, has accounted for relatively few failures over periods of up to 12 years (Sturdevant & others, 1988; Bayne & others, 1989; Letzel, 1989; Moffa, 1989b) and, although it was possible in one study to find a very strong correlation between occlusal wear and recurrent caries (on nonoccluding surfaces), no direct cause and effect relationship was obviously present (Taylor & others, 1992). Far less information is available on predicting failure modes for anterior composite restorations in clinical trials. The most common and sometimes fairly high failure modes reported (where restoration retention did not depend on dentin adhesives) have usually been caries, marginal fracture and staining, then color mismatches. Except for incisal restorations, bulk fractures were uncommon (van Dijken, 1986; Qvist & Ström, 1988; Van Noort, Davis & Barker, 1988; Smales & Gerke, 1992).

For amalgam restorations the marginal fracture of some alloys has been associated, sometimes tenuously, with bulk fractures (Osborne, Binon & Gale, 1980; Lemmens & others, 1987; Letzel & others, 1989) and with marginal caries, especially if the marginal fractures were severe occlusally (Maryniuk & Brunson, 1989), or were located gingivally in class 2 restorations (Goldberg & others, 1981), or were associated with poor oral hygiene (Eriksen, Bjertness & Hansen, 1986). However, other studies have been unable to find any such significant relationships (Bailit

& others, 1979; Hamilton & others, 1983; Söderholm, Antonson & Fischlschweiger, 1989; Foster, 1990; Jokstad & Mjör, 1991). In one study, the percentage of secondary caries was only 7% for amalgam occlusal margins and 38% for composite incisal margins, the remaining lesions being found at the cervical and approximal margins (Mjör, 1985).

In the present study, although a very strong association was found between the occlusal surface tarnishing of the amalgams and subsequent failures, the restorations were rarely replaced directly because of this problem (Table 2). However, perhaps surface tarnishing may, in some instances, reflect the effects of underlying corrosion of the restorations, leading to later bulk fractures. Despite the strong association found, it is highly unlikely that occlusal surface roughness directly affects marginal caries. The lack of a strong association between occlusal marginal staining or marginal fracture and later restoration failure demonstrates the relatively minor role of these two clinical factors as a direct reason for amalgam replacements.

Studies of anterior composite restorations have also reported conflicting associations, between either marginal fracture or marginal staining and marginal caries (van Dijken, 1986; Kidd, 1991; Smales, 1991).

For the anterior composites in the present study, although a very strong association was found between surface roughness and later failures, the restorations were rarely replaced because of this problem, which also appears to be an unlikely cause of restoration fracture (Table 3). When present, marginal fractures were usually minor, and most obvious on the palatal margins of restorations placed in maxillary incisors, seldom requiring replacement of the restorations. Perhaps marginal fractures may, in some instances, later lead to marginal caries, and may also reflect the effects of occlusal stresses on the restorations, which subsequently show bulk fracture. Although color mismatch was also very strongly associated with subsequent failures, it seems unlikely that such discoloration could be a cause of restoration fracture. Marginal staining was usually superficial, and most noticeable on the palatal aspect of restorations placed in heavy smokers, as was surface staining.

The continued long-term functioning of many restorations deemed as being unsatisfactory for various clinical factors showing restoration deterioration requires a re-appraisal of what constitutes restoration failure (Table 4). Clearly, there is a need to define unsatisfactory quality restorations in terms of any evidence of actual adverse effects on dental health for functional, esthetic, or biological reasons, rather than merely in terms of deterioration of the restorative materials.

Most of the clinical factors presently used to assess the deterioration of the amalgam and composite restorative materials used in this study, and possibly in other studies also, would appear to have little direct relevance for predicting restoration replacements. Because of the problems of reliably predicting restoration failures merely by observing restoration deterioration, a modification of the standard Weibull distribution function has been suggested for use in estimating predictions of long-term restoration survivals that are based on their actual earlier failure behavior (Smales, Webster & Leppard, 1991a,b). It was found that, provided around 4 - 6% of restorations failed in any period, the method could give reasonably accurate predictions of future long-term survivals.

CONCLUSIONS

From the evaluations of the long-term deterioration and failure behavior over periods of up to 16 years for a large number of amalgam and anterior resin composite restorations placed in numerous patients, it was found that:

1. The percentages of restorations rated as being unsatisfactory for each clinical factor assessed were relatively low. The most frequent reasons for unsatisfactory assessments were surface tarnishing (9.8%) for the amalgams and color mismatches (8%) for the composites.

2. For the amalgams, there was a significant association found between the failures and surface tarnishing. For the composites, there were significant associations found between the failures and surface roughness, marginal fracture, and color mismatch. But strong associations between different factors

do not necessarily imply that direct cause and effect relationships are present. The percentage of failures, for the amalgam especially, was relatively low.

3. Many unsatisfactory restorations continued to function adequately for a further 2.5 to 3.5 years on average after such designations before they were replaced, often for unrelated reasons.

4. Therefore, there is a need to define unsatisfactory quality restorations more clearly in terms of any evidence of actual adverse effects on dental health for functional, esthetic, or biological reasons, rather than merely in terms of deterioration of the restorative materials.

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Adhesive Interface between Resin and Etched Dentin of Cervical Erosion/Abrasion Lesions

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Y SHIMADA • H HOSODA

Clinical Relevance
A thinner hybrid layer is seen in the occlusal portion of erosion/abrasion lesions. Further research is needed to determine the clinical relevance.

SUMMARY

The interfacial structure between an adhesive composite resin and the dentinal walls of cervical erosion/abrasion lesions etched with 37% phosphoric acid gel for 60 seconds was investigated. Almost all dentinal tubules were occluded with rod-like structural depositions that remained undissolved even after acid conditioning. The hybrid layer between the adhesive resin and surface-demineralized dentin was found to be 0.3 to 3 μm, much thinner than that routinely found in either normal dentin or cariously affected dentin. The hybrid layer was thinnest at the occlusal walls of the cavity where the dentinal tubules run parallel to the cavity surface. The bond strength of adhesive resin to these areas may differ from that to intact normal dentin.

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INTRODUCTION

The essential mechanism of adhesion between current dentin bonding systems and the dentin substrate has been suggested to be the formation of a hybrid layer made up of resin that has impregnated into the superficial decalcified dentin surface (Nakabayashi, 1984). The morphological variations of the hybrid layer in several current dentin bonding systems were revealed using an argon ion beam etching technique (Inokoshi & others, 1990, 1992; Van Meerbeek & others, 1992). A subsequent study of the interface between resin and caries-affected dentin also revealed the presence of the hybrid layer, which showed wider variations than that of normal ground dentin. This was due to structural changes of carious dentin (Harnirattisai & others, 1992). To date, unfortunately, limited information is available with regard to the interface between the adhesive resin and dentin that has been altered by vital pulp reaction to exogenous stimuli such as observed in the case of cervical erosion and abrasion. It is particularly in this type of lesion where the use of dentin bonding agents may have the greatest benefit clinically.

This in vitro study was designed to observe the interfacial structure between an adhesive resin and the dentin of cervical erosion/abrasion lesions using the previously described technique (Inokoshi & others, 1990, 1992; Harnirattisai & others, 1992).

METHODS AND MATERIALS

Ten caries-free upper first premolars exhibiting cervical erosion/abrasion lesions were used. They were extracted for periodontal reasons from 49- to 68-year-old patients and stored in normal saline at 4 °C until used. The depths of the erosive/abrasive lesions were categorized by theoretically dividing the dentin thickness into thirds. The depth of the V-shaped defect reached the middle third of the dentin in four teeth and the inner third of the dentin in the remainder of the teeth. The dentinal walls of the lesion were cleaned using a fine pumice slurry and slowly rotating bristle brush to remove any residual contamination. The walls were conditioned using 37% phosphoric acid gel for 60 seconds, washed with air-water spray for 10 seconds, and air-dried for 15 seconds prior to the application of an adhesive resin (Clearfil Photo Bond, Kuraray Co, Osaka, Japan). This was light cured for 30 seconds. A visible-light-cured low-viscosity composite resin (Protect Liner, Kuraray Co) was used to cover the lesion in a thin layer (less than 0.5 mm) and light cured for 60 seconds. No further placement of restorative composites was performed in order to avoid separation of the adhesive resin from cavity walls due to polymerization shrinkage.

The specimens were stored in 10% neutral buffered formalin for 24 hours, then washed in running tap water before being buccolingually sectioned through the center of the lesion with a diamond saw (Leitz 1600 saw microtome, Ernst Leitz Wetzlar Co, Germany) under water coolant. The two halves of each saw-cut specimen were embedded in epoxy resin and then polished with wet silicon carbide papers and diamond pastes of decreasing abrasiveness down to 0.25 μm. Ten pairs of specimens were obtained. One half of each pair was subjected to argon ion beam etching (EIS-1E, Elionix Ltd, Tokyo, Japan) for 10 seconds. The operating conditions for the ion source were the same as previously reported. These specimens were then gold coated and observed by scanning electron microscopy (SEM) (JXA-840, JEOL Ltd, Tokyo, Japan).

In order to clarify the relationship between surface hardness of the lesion and the depth of the resin-impregnated layer, the opposing half of the same tooth was subjected to a Knoop hardness test (MVK-E Hardness Tester, Akashi Co, Tokyo, Japan). The Knoop hardness number (KHN) could not be measured exactly at the lesion surface, so recordings were made 50 μm below the lesion surface, which still approximates the hardness of the cervical erosion/abrasion lesion's surface. Indentations were made 50 μm beneath the resin-dentin interface by applying a 50-gram load for 15 seconds. The measuring points were the outer, middle, and inner third of the dentin along the occlusal and gingival walls of the lesion. Four points were measured for medium defects and six points for deep defects. A total of 52 points were selected for measurement in the 10 teeth. After the measurements were completed, these specimens were similarly prepared and observed using the scanning electron micrograph (SEM). The depth of the resin-impregnated demineralized dentin layer above the Knoop hardness indentations was measured directly from the SEM photographs, using the SEM micrograph magnification bar. The relationship between the depth of the resin-impregnated layer and KHN at 50 µm beneath the dentinal wall was analyzed using liner regression statistics.

The effect of tubule orientation on the demineralization of the lesion surface with phosphoric acid was analyzed by calculating the statistical differences of the depth of the resin-impregnated layer between the occlusal and gingival walls of the outer and middle third of the dentin.

RESULTS

SEM Observation: Morphological Findings Were Obtained from the Longitudinally Cut Center Sections.

Most dentinal tubules of the gingival and occlusal walls were occluded by rod-like structural depositions. At the gingival walls (Figure 1), the direction of dentinal tubules was at right angles to the wall surface, and the depth of the hybrid resin-impregnated layer (RIL) was found to be in the range of 1 to 3 µm. The depth of this layer appeared to be uniform throughout the wall. Resin tags were seldom observed, and when present, were noted to be extremely short.

Morphological variations of the interface were found more often at the occlusal wall, where the direction of the dentinal tubules varies from an oblique direction near the deepest part, gradually becoming parallel toward the dentinoenamel junction. Resin tags were, again, rarely observed in this wall. The depth of the resin-impregnated layer was within the range of 0.3 to 2 µm. The thinnest part was always found at the interfacial zone just beneath the dentinoenamel junction (Figure 2), with the exception of an area that appeared to be interglobular dentin. In this region, the RIL was wider and irregular in appearance (Figure 3). In some areas where dentinal tubules run parallel to the lesion surface, the entire length of the intratubular deposits was found embedded in the hybrid

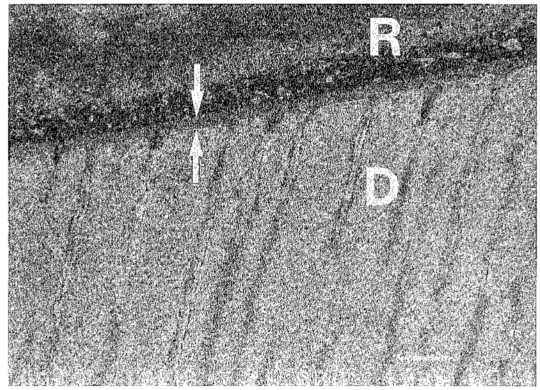

Figure 1. *SEM image of the resin-dentin interface from the area of the gingival wall after argon ion beam etching (R = resin, D = dentin). The resin-impregnated intertubular dentin (RIL) is approximately 2 µm in depth (arrow). Bar = 10 µm.*

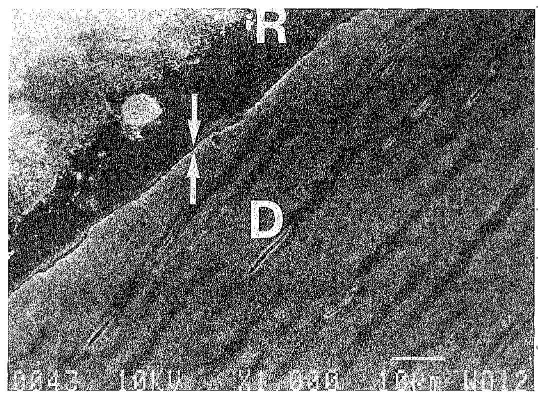

Figure 2. *SEM image of the resin-dentin interface from the region close to the dentinoenamel junction of the occlusal wall. The depth of the RIL (arrow) is approximately 0.5 µm. Bar = 10 µm.*

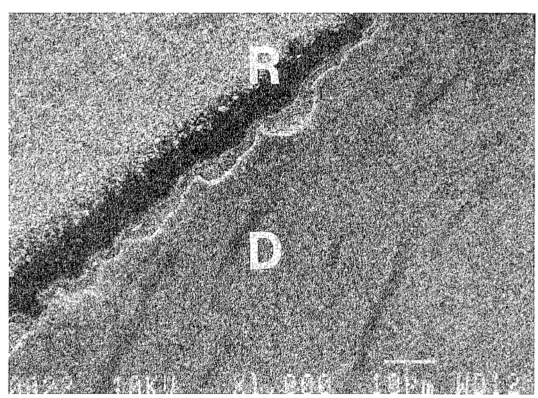

Figure 3. *SEM image illustrating the resin-dentin interface from the area of interglobular dentin in the peripheral part of the occlusal wall, after argon ion etching. Note the irregular and thick RIL. Bar = 10 µm.*

layer (Figure 4). Small crevices were observed, mainly on the occlusal walls in several specimens (Figure 5).

Correlation between the Depth of the RIL and Knoop Hardness

Forty-eight sets of data were obtained. Four of the 52 points were lost due to separation at the resin-dentin interface. No statistically significant relationship between the RIL depth and Knoop hardness of the walls was found (Figure 6). However, the depth of the RIL of the gingival wall (mean depth = 1.84 μm, SD = 0.85 μm, range = 0.70 - 4.56 μm, n = 20) was significantly greater than that of the occlusal wall (mean depth = 1.01 μm, SD = 0.58 μm, range = 0.26 - 2.10 μm, n = 17) (Mann-Whitney U test, $P < 0.01$).

DISCUSSION

Many studies have reported variations in the degree of tubular occlusion of the cervical erosion/abrasion. Even in sensitive lesions, it was noted that approximately 80% of the tubules were obliterated and 20% were patent (Yoshiyama & others, 1989). However, most specimens used in this study had nearly all of the dentinal tubules adjacent to the surface of the lesion occluded. This is probably due to the population of the teeth, which were extracted for periodontal reasons from older patients. In the occluded tubules, the penetration of bonding resin into the tubules was limited by the undissolved intratubular deposits. A small number of tubules with patent lumina were scattered randomly throughout the sclerotic region, which accounts for the scarcity of resin tags.

The resin-impregnated demineralized layer (RIL) of the cervical erosion/abrasion lesions appeared to be thinner than that of the carious excavated dentin, which was found to be from 1 to 8 μm (Harnirattisai & others, 1992). This discrepancy may be partially dependent on the percentage of tubules that were occluded.

Since regional variations in mineralization content such as an area of interglobular dentin were noted to produce a thick irregular RIL, the depth of RIL seems to depend on the degree of mineralization. However, there was no clear relationship between the

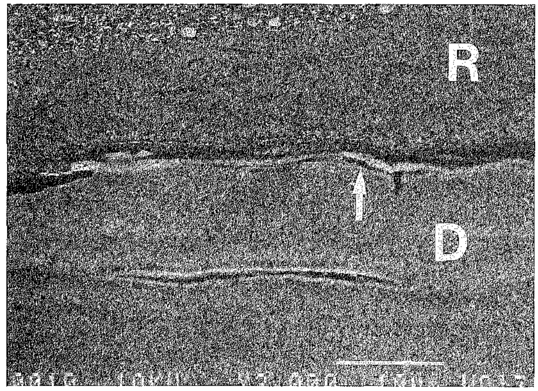

Figure 4. *SEM image of the resin-dentin interface from the occlusal wall after ion etching, showing the remnants of intratubular deposits that remain in the RIL. Note the presence of microspaces (arrow) between the rod-like deposits and the underlying undemineralized dentin. Bar = 10 μm.*

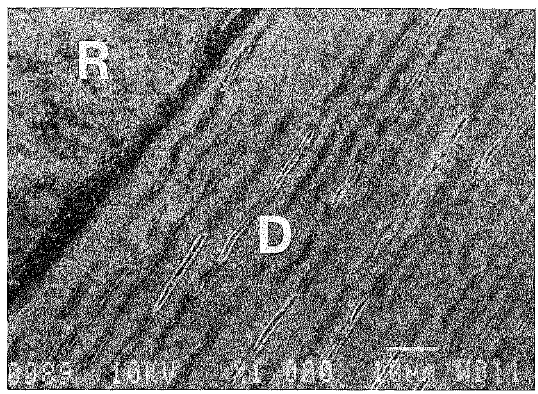

Figure 5. *SEM image of the resin-dentin interface from the occlusal wall after ion etching shows small perpendicular microcrevices extending 3 - 7 μm from the RIL into adjacent dentin. Bar = 10 μm.*

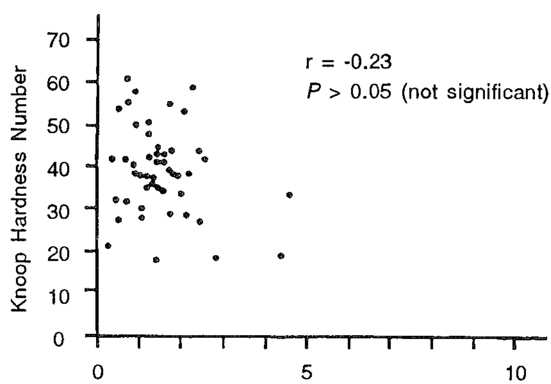

Figure 6. *Relationship between the depth of the RIL and the Knoop hardness of dentin*

hardness of the lesion surface and the depth of RIL. The Knoop hardness ranged from 20 to 60, which is similar to that of the cavity floor after caries excavation. Within this range of hardness, demineralization of superficial dentin by conditioning or etching agents appears to be independent of the hardness of the dentin substrate.

Although most tubules were obliterated, the direction of the tubules seems to play an important role for demineralization of superficial dentin. The occlusal wall, where dentinal tubules run parallel to the lesion surface, exhibited significantly thinner RIL than the gingival wall. This finding is similar to the previous study on caries-affected dentin (Harnirattisai & others, 1992).

An interesting anatomical variation in the occlusal wall was the presence of a long rod-like intratubular structure inside the RIL, as seen in Figure 4. A small space was observed between this calcified structure and the subjacent undemineralized dentin. This microspace may be an artifact caused during desiccation of the specimen, but many studies (Lester & Boyde, 1968; Isokawa, Kubota & Kuwajima, 1973; Vasiliadis, Darling & Levers, 1983) have reported the existence of an annular space between the rod-like structure and the surrounding dentin, especially those cases where the rod has a diameter less than that of the lumen of tubules. If the bonding resin is unable to penetrate and fill this space, this region could be subject to microleakage and subsequent adhesive failure.

It is of clinical interest that the bond strength of some current dentin bonding systems has always been determined using intact dentin where the dentinal tubules are patent. However, for sclerotic dentin, almost all tubules were occluded. This suggests that the adhesion between the sclerotic dentin and bonding resin appeared to rely almost solely on resin impregnation into the demineralized intertubular dentin. This may partly explain inferior retention of adhesive composite restorations in these lesions (Duke & Lindemuth, 1991). The cervical erosion/abrasion lesion is, thus, the most suitable substrate for examining the efficacy of those current dentin bonding systems where the bonding mechanism is believed to be reliant on RIL.

Several studies (Lee & Eakle, 1984; Lambrechts, Braem & Vanherle, 1987; Meyer, Dawid & Schwartz, 1991; Heymann & others, 1991) have demonstrated that the tensile stress created during mastication and parafunctional movements causes the flexure of teeth. It is conjectured that this may subsequently cause dental hard tissue defects that might lead to wedge-shaped lesion formations. These defects are characterized by axial enamel rod fractures with formation of microcracks. This process continues even after the formation of the lesions and may be responsible for the small crevices that are noted in several specimens (Figure 5) that appear to be related to the incremental lines of the dentin. It is known that those lines are regions of varying calcification. The location of the lesion could therefore be an area that is structurally weakened within the tooth, hence becoming the point of initial breakdown during flexing of the tooth. A previous study has noted that these lesions are the sites where initial bacterial invasion occurs in the case of cervical caries (Wang, 1991).

In the present study, morphological analysis of the interface between an adhesive resin and cervical erosion/abrasion lesions was performed only on the center section of the teeth; not all of the lesion's surface was examined. The population of samples was also limited to insensitive premolars extracted for periodontal reasons from older patients. Further analysis of resin/dentin interfaces should be performed to observe other parts of the lesions, and also on hypersensitive teeth.

CONCLUSIONS

The interface between an adhesive resin and the dentinal walls of cervical erosion/abrasion lesions after acid etching was observed. SEM observation of the specimen subjected to argon ion beam etching revealed the hybrid layer of resin-impregnated intertubular dentin with a thickness range of between 0.3 to 3 μm. Few resin tags were found. A thinner hybrid layer with a variable morphology was observed on the occlusal wall of the lesions.

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ANNOUNCEMENT

Ms (Kate) Flynn Connolly, the journal's Editorial Associate, is publishing her first science fiction novel through Del Rey Books, New York. ***The Rising of the Moon*** will be available through your local bookstores in August. Ms Connolly's book is the first of a proposed series and deals with a future revolution in Ireland. Kate has been working with our journal for the past seven years and has greatly enhanced the quality of the journal through her expertise.

OPERATIVE DENTISTRY, 1993, 18, 144-147

Composite Resin Bond Strength after Enamel Bleaching

F GARCÍA-GODOY • W W DODGE
M DONOHUE • J A O'QUINN

Clinical Relevance
The shear bond strength of composites to enamel can be significantly reduced after bleaching. Delaying bonding procedures or grinding the superficial bleached enamel prior to bonding is recommended.

SUMMARY

This study evaluated the effect of enamel bleaching with a commercial product on the sheer bond strength of a composite resin. A total of 45 human extracted permanent molars were used. A flat enamel surface was obtained with 600-grit SiC paper. The teeth were then randomly distributed into three groups of 15 teeth each: Group 1: Enamel etching with 37% phosphoric acid gel (Coe) for 60 seconds, placement of an unfilled resin (Coe) thinly applied with a brush and a composite resin (Occlusin); Group 2: Enamel bleaching (Rembrandt Lighten Bleaching Gel, Den-Mat) for one hour, etching for 60 seconds and placement of unfilled and composite resins. Group 3: Enamel bleaching for 24 hours, etching for 60 seconds, and placement of unfilled and composite resins. A nylon ring over the etched enamel retained the composite resin. The teeth were thermocycled (X100) and sheared with a knife-edged blade in an Instron machine running at a cross-head speed of 1 mm/min. The results in MPa were: Group 1: 12.86 ± 4.83, Group 2: 12.33 ± 2.95, and Group 3: 7.67 ± 1.98. An ANOVA revealed that Groups 1 and 2 were significantly different from Group 3 ($P < 0.001$). Fracture within the enamel occurred in 53% in Group 1, 33% in Group 2, and 0% in Group 3. The study reveals

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that the shear bond strength of composite resins is significantly reduced after enamel bleaching for 24 hours.

INTRODUCTION

The treatment of hypoplastic and discolored enamel has been described by many authors. The bleaching action of agents such as concentrated hydrogen peroxide (superoxyl) with heat application, diethyl ether, sodium hypochlorite, hydrochloric acid, or combinations of these agents have been used (Ames, 1937; Bailey & Christen, 1968, 1970; Colon, 1971, 1973; Chandra & Chawla, 1975; Wayman & Cooley, 1981; Jordan, Suzuki & Gwinnett, 1981; Murrin & Barkmeier, 1982; Jordan & Boksman, 1984; Croll & Cavanaugh, 1986; McInnes, 1966; Mathewson, Morrison & Carpenter, 1987; Kapila & Currier, 1988; Haywood & Heymann, 1989).

Recently, a technique for home use consisting of a carbamide peroxide gel in a tray is available (Rembrandt Lighten[a]) and is claimed to be a safe, nonacidic tooth bleaching and whitening system.

In some cases, after bleaching procedures, the color obtained is not clinically acceptable and an esthetic restoration must be placed using the acid-etch technique. Because bleaching procedures interact with the enamel, bonding of some of these esthetic restorations to bleached enamel could be compromised (Cvitko & others, 1991). Additionally, the effect of bleaching agents over previously placed composites adversely affect the marginal seal (Crim, 1992).

The purpose of this study was to evaluate the effect of enamel bleaching with a carbamide peroxide gel on the shear bond strength of a composite resin.

METHODS AND MATERIALS

A total of 45 human extracted permanent molars stored in distilled water were used. A flat enamel surface was obtained with 600-grit SiC paper. The teeth were then randomly distributed into three groups of 15 teeth each:

Group 1: Acid etched with 37% phosphoric acid gel (Coe Laboratories, Chicago, IL 60658) for 60 seconds, followed by placement of an unfilled resin (Coe) thinly applied with a brush and a composite resin (Occlusin, Coe).

Group 2: Immersion for one hour in a 10% carbamide peroxide bleaching agent (Rembrandt Lighten Bleaching Gel, Den-Mat, Santa Maria, CA 93456) in a sealed container at room temperature, rinsed and dried, acid etched with 37% phosphoric acid gel for 60 seconds followed by placement of unfilled and composite resins.

Group 3: Immersion for 24 hours in the bleaching agent (Rembrandt Lighten Bleaching Gel) in a sealed container at room temperature, rinsed and dried, acid etched with 37% phosphoric acid gel for 60 seconds followed by placement of unfilled and composite resins.

After acid etching, the teeth were rinsed with water for 20 seconds and dried with compressed air for 20 seconds. The unfilled resin was thinly applied with disposable brushes, gently blown with compressed air, and cured for 30 seconds. A nylon ring (1/8" long, 0.187" in outer diameter and 0.115" in internal diameter) placed over the area was filled with the light-cured composite resin. The ring with the composite resin was light cured for three 30-second exposures: one from each side and one from the top. After curing, the teeth with the rings bonded to the enamel were immersed in water for 72 hours and then thermocycled for 100 cycles (one cycle = two 30-second exposures in cold water and two 30-second exposures in hot water) in temperatures ranging from 5 °C to 55 °C. Immediately, the specimens were mounted in plastic cups with plaster in a position that allowed the shearing force to be exactly perpendicular to the bonded ring. After 15 minutes the specimens were sheared with a knife-edged blade in an Instron machine running at a crosshead speed of 1 mm/min. The results were recorded in megapascals (MPa). After shearing the specimens, each tooth and composite interface were examined visually and at X40 with a dissecting microscope to record the failure mode. The Analysis of Variance and the Student-Newman-Keuls procedure were used to evaluate the results.

RESULTS

The results revealed that enamel acid etched for 60 seconds prior to bonding or bleached for one hour before acid etching had no significantly different bond strength (12.86 ± 4.83 MPa and 12.33 ± 2.95 MPa respectively) (table). The ANOVA showed that Groups 1 and 2 were significantly different from Group 3 ($P < 0.001$).

Fracture within the enamel (enamel cohesive failure) occurred in 53% of Group 1, 33% of Group 2, and 0% of Group 3. In Groups 1 and 2, the remaining specimens showed a mixed failure mode.

DISCUSSION

Exposure of human tooth enamel to hydrogen peroxide for 60 minutes produced changes in surface morphology (Titley & others, 1988). This would seem clinically relevant, as periods of two hours are recommended for bleaching some discolored teeth (Titley & others, 1988). The 24-hour immersion in the peroxide gel was selected because it is recommended for long-term use (four to six weeks) by the patient at home with a tray. Because the lower bond strength was obtained with the 24-hour immersion, a similar trend should be expected if exposed for longer periods. Another aspect of this study, similar to that of Titley and others (1988), was that immersion rather than surface application of the carbamide peroxide gel was chosen to ensure uniform exposure of the enamel.

This study, conducted in human teeth, shows that enamel immersed for 24 hours in a carbamide peroxide gel reduces the shear bond strength of the composite resin tested.

Shear bond strength (in MPa) for the different groups

Group	Number	Mean (MPa)	S.D.	Range
Nonbleached	15	12.86	4.83	5.81 - 19.90
Bleached for 1 hour	15	12.33	2.95	5.70 - 17.51
Bleached for 24 hours	15	7.67	1.98	4.90 - 13.06

A previous study in bovine enamel showed that a one-hour exposure to hydrogen peroxide caused a significant reduction in the bond strength of a composite resin. Although the two studies used human or bovine enamel and the results are difficult to compare, the neutral pH of the carbamide peroxide gel could be the reason why a one-hour exposure to the gel had no significant effect on bond strength as compared to hydrogen peroxide. However, when analyzing the fracture site, it is evident that the group treated with the carbamide peroxide gel produced adhesive failures more frequently than the acid-etched group not treated with the peroxide gel. The nonbleached group displayed more cohesive failures (composite-enamel). Although a reduced bond strength is obtained after bleaching the enamel, it does not seem to be related to the peroxide-induced change in the elemental composition of the enamel surface (Ruse & others, 1990).

The bleaching agent used in this study is a neutral (pH 6.8) 10% carbamide peroxide gel. In the bleaching process, carbamide peroxide reacts with water to release hydrogen peroxide. Peroxides decompose into free radicals, which in turn break down large pigmented molecules into smaller, less pigmented ones. The lower bond strength obtained after bleaching the enamel could be due to a chemical change in the enamel that interferes with the acid-etching technique. Also, the interaction of the bleaching agent with saliva could produce different clinical results. Further clinical studies should evaluate the significance of the results observed in this in vitro evaluation.

The results obtained in the present study are clinically relevant because discolored teeth that have been bleached may regress in two to three years (Feinman, Goldstein & Garber, 1987), requiring rebleaching or another type of treatment, possibly using the acid-etch technique. The lower bond strength noted in this study after a 24-hour exposure to the bleaching agent should be taken into consideration by the clinician to avoid a potentially significant rise in treatment cost to the patient. The clinician should select the cases of enamel discoloration to be treated with the bleaching technique. The procedure appeared to be more effective when treating yellow, orange, or slightly brown teeth. Darker gray, blue, and/or dark brown stains do not respond as well (Corcoran & Zillich, 1974).

Recent studies have shown that the adverse effect of bleaching agents on the shear bond strength of resin composites to enamel will dissipate after 48 hours (Godwin & others, 1991) or after grinding the superficial bleached enamel surface (Machida & others, 1992); therefore, these results should be considered prior to bonding resins to bleached enamel.

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OPERATIVE DENTISTRY, 1993, 18, 148-154

A Clinical Trial to Evaluate the Retention of a Silver Cermet-Ionomer Cement Used as a Fissure Sealant

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Clinical Relevance
Cermet-ionomers function well as dental sealants.

SUMMARY

A randomized clinical trial was undertaken to compare the retention of a silver cermet-ionomer cement, Ketac Silver, with a conventional, autopolymerizing BIS-GMA resin sealant, Delton, using matched pairs of fissure sites within each subject's mouth. One hundred twenty matched contralateral pairs of fissure sites in first and second permanent molars of 53 school children were sealed with the two materials. The choice of site and material was selected at random. The ages of the children ranged from five to 16 years; first permanent molars were sealed in the five- to 10-year age group, and second permanent molars in the 11- to 16-year age group. Sealants were assessed as present, partly present, or absent at 6, 12, and 24 months.

The number of pairs of sites available for reassessment declined from 102 at six months to 59 at 24 months as patients were lost to the study. Retention rates were higher for the Ketac Silver sealants at all three inspection intervals ($P < 0.01$): 93% compared with 74% at six months, 81% compared with 65% at 12 months, and 83% compared with 58% at 24 months. When analyzed according to age range, the difference between the retention rates was statistically significant in the five- to 10-year-olds but not significant in the 11- to 16-year-olds. The conclusion reached in this study was that cermet cement was better retained than conventional resin sealants in younger children.

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INTRODUCTION

In spite of the encouraging decline in the incidence of dental caries in children in the United Kingdom (Todd & Dodd, 1983), there still remains an undisputed need for the continuing use of sealants in children in selected situations (Ripa, 1990).

Caries is becoming predominantly a disease of pits and fissures (Bohannan & others, 1984), a change that is thought to be attributable to the increased exposure of teeth to fluorides, which confer greater protection to smooth surfaces than to pits and fissures. Thus, with the judicious use of sealants, it is now feasible to render an increasing number of children caries-free.

The effectiveness of sealants correlates well with their retention (Metz-Fairhurst, 1984; Rock, 1984), and therefore the measurement of retention rates provides a useful method of evaluating the effectiveness of one sealant against another.

The BIS-GMA autopolymerizing clear resin sealant Delton (Johnson & Johnson Ltd, Maidenhead, UK) was the material chosen to serve as a benchmark against which the performance of the silver cermet-ionomer cement Ketac Silver (ESPE GmbH, Seefeld/Oberbay, Germany) could be gauged, principally because it is widely employed in clinical practice and has been used in many previous clinical trials (Houpt & Shey, 1983; Ripa, 1985).

The numerous factors that affect the retention of sealants have been reviewed elsewhere (Ball, 1979a,b) and include operator variability, patient age and co-operation, contamination of the field of operation with saliva, the presence of oil and/or water vapor in the compressed air used to dry the etched tooth surface, etc. This latter problem is one that may escape the notice of the operator unless it is specifically looked for, but it has been overcome to a large extent in recent years by the development of the oil-free compressor fitted with a dessicator.

Glass-ionomer cements have been used as fissure sealants in previous clinical trials (McLean & Wilson, 1974; Williams & Winter, 1976; Williams, Price & Winter, 1978; Smales, 1981; Shimokobe & others, 1986; McKenna & Grundy, 1987; Widmer & Jayasekera, 1989) with and without mechanical preparation of the fissures with variable success (Table 1). They were initially advocated for use in wide fissures where the normally viscous material could be diluted and forced into the fissures by mechanical means.

It was anticipated that advantageous properties such as chemical bonding with enamel and the ability to leach fluoride would make glass-ionomer cement the ideal material for sealing fissures. However, due to inherent, low wear resistance, low cohesive strength, and increased solubility, the material lacked the ability to sustain long periods in the mouth when used in these situations.

Cermet-ionomer cement was developed as an improvement on glass-ionomer cement, and the incorporation of sintered particles of silver was believed to impart superior physical properties, particularly in relation to wear resistance (Wilson, Prosser & Powis, 1983), making it a more suitable choice of material for small single-surface posterior restorations. Thus the most appropriate application for this new material would be the sealant restoration. However, it was still not known how such a material would withstand the demanding situation of being used in thin sections as a fissure sealant.

Table 1. Sealant Studies Using Glass-Ionomer Cements

Investigator	% Retention 6 Months	12 Months	Type of Sealant
Smales (1981)	-	100	ASPA
McLean & Wilson (1974)	-	86	ASPA
Widmer & Jayasekera (1989)	-	85	-
McKenna & Grundy (1987)	93	82	Ketac-fil
Williams & others (1978)	64	54	ASPA IV
Williams & Winter (1976)	42	30	ASPA II
Shimokobe & others (1986)	0	0	-

METHODS AND MATERIALS

The evaluation of a material or technique is best achieved by keeping as many factors involved as possible common to both the test and control groups; thus, the same mouth and same operator go some way towards this goal. The design allowed for a degree of quantitative as well as qualitative assessment of sealant retention performance by giving scores to each site so that matched pairs for test and control groups could be compared.

The intentional design of the trial was such that each cermet-ionomer cement sealant would have its own resin control sealant at the contralateral site of the same mouth for direct comparison. Jorgensen (1975) has shown that the corresponding enamel surface sites of contralateral teeth are structurally the same and exhibit identical etched patterns.

The appearance of the two materials used in this trial was quite different, and therefore it was not possible to make the study of double-blind design; the autopolymerizing BIS-GMA resin was clear, whereas the cermet-ionomer cement was light gray and opaque.

Sealants were placed, assessed, and photographed by one operator during the course of routine treatment. A total of 53 children between the ages of five and 16 years who were attending a community dental clinic were selected to participate in the clinical study. Approval was obtained from the district Ethics Committee, and in order for children to be included in the trial, agreement by both the child and the accompanying parent was required. The first 53 children to satisfy the clinical criteria and who agreed to participate in the trial were accepted for treatment and retained in the trial regardless of how difficult subsequent treatment proved to be.

Each child entering the trial required at least one pair of contralateral caries-free fissure sites. Discrete pit and fissure sites identified for this purpose were: the occlusal fissure distal to the oblique ridge of maxillary molars, the occlusal fossa mesial to the oblique ridge in maxillary molars, the occlusal fissure in mandibular molars, and the buccal groove or pit in mandibular molars.

Random allocation of both the sites to be sealed and the choice of material to be used at each site was decided by the dental surgery assistant, Julie McKinnon, spinning a coin. The teeth were isolated with cotton wool rolls and saliva ejector. All sites for both materials were similarly etched for 60 seconds using the etching solution supplied in the Delton kit, washed for 15 seconds and dried for 30 seconds with a three-in-one syringe before applying the sealant.

Delton was mixed and applied in accordance with the manufacturer's instructions. The encapsulated Ketac Silver was also mixed according to the manufacturer's instructions and applied directly into the fissures from the nozzle of the capsule, which was held in an applicator. It was then smeared and compressed into the fissures using a gloved finger or plastic instrument. Excess cement was purposely left on the tooth until set and occlusal adjustment was then made as appropriate using a round diamond bur in a slow-speed handpiece with water coolant.

Sealants were evaluated after 6, 12, and 24 months using a conventional mouth mirror and probe and were recorded as present (fissure pattern completely covered), partly present, or absent, and each category was ascribed a value of 2, 1, or 0 respectively. This enabled the use of the Wilcoxon Matched Pairs Signed-Rank Test to contrast the performance of the two materials. Where Ketac Silver was retained to a greater degree than Delton this was recorded as a positive value, and where the converse was true, a negative value. The difference between scores for all matched pairs in the study was calculated (those with identical scores being excluded) and these placed in rank order. The sum of the ranks was calculated, and the statistical significance of the difference between the matched pairs read off from statistical tables.

RESULTS

An increasing number of subjects were lost to the trial at each subsequent review with 43 of the original 53 children being available for inspection at six months. At six months 102 pairs of sealants were examined out of a total 120 sealed; this declined to 99 pairs at 12 months and 59 pairs at 24 months. Most of the children lost to the study were in the 11- to 16-year age group.

Taking all the children in both age groups, the cermet-ionomer cement sealants showed a significantly greater retention rate at all review intervals. Thus the percentage retention for Ketac Silver was 93% compared with Delton's 74% at six months, 81% compared with 64% at 12 months, and 83% compared with 58% at 24 months (Table 2).

When the data were analyzed according to age group, a statistically significant difference between the retention rates of the two materials was observed in favor of Ketac Silver in the younger age group, but no difference was seen between retention rates for the older age group.

For example, at 12 months in the five- to 10-years-olds Ketac Silver achieved a retention rate of 83% and Delton 66%, which was significant by the Wilcoxon Matched Pairs Signed-Rank Test ($P < 0.01$); however, in the 11- to 16-year age group there was no significant difference between the Ketac Silver at 11% and Delton at 62% ($P < 0.2$) (Table 3).

The sites sealed in the five- to 10-year age group were first permanent molars, whereas the sites sealed in the 11- to 16-year age group were second permanent molars. No teeth sealed as part of this study developed pit or fissure caries during the course of the trial.

Figures 1-4 show a Ketac Silver sealant after different intervals up to 48 months.

Table 2. Overall Results for Children in Both Age Groups Using the Wilcoxon Signed-Rank Test

	Present		Partly Present		Absent		Total Sites
	n	%	n	%	n	%	n
Total Sites after 6 Months							
Delton	76	74	15	15	11	11	102
Ketac Silver	95	93	3	3	4	4	102
$P < 0.01$							
Total Sites after 12 Months							
Delton	64	65	18	18	17	17	99
Ketac Silver	80	81	13	13	6	6	99
$P < 0.01$							
Total Sites after 24 Months							
Delton	34	58	10	17	15	25	59
Ketac Silver	49	83	6	12	4	6	59
$P < 0.01$							

DISCUSSION

The sites sealed with Ketac Silver were etched in an identical manner to those for Delton resin. Glass-ionomer cements are noted for their adhesive properties to enamel as well as dentin. Where pellicle remains interposed between the material and the tooth, this compromises adhesion. Phosphoric acid dissolves a few microns of the surface layer of enamel, detaches the pellicle, and leaves it in a more reactive state with an affinity to bond to materials with which it may then come into contact (Gwinnett, 1984).

The retention rates for the Delton resin were lower than expected when compared with most other studies using the same material. It is possible that some sealants were not detected because they were translucent and therefore not so readily visible. Rock and others (1989) demonstrated in a retrospective clinical trial that clear sealants were often misinterpreted compared with opaque or white sealants. It might therefore have been preferable to use an opaque sealant as a control.

Ketac Silver cement is several times more expensive than Delton resin and takes longer to set (about five to six minutes from initial mixing). These factors might detract from its routine use as a sealant. However, if used in the placement of sealant restorations where the entire restoration and sealant can be completed with one mix and in the same procedure, this material becomes a more commercially viable proposition. Additionally, glass-ionomer cements possess cariostatic activity that would be a valuable asset in this situation.

Over a two-year period cermet-ionomer cements appear to perform better than resin sealants in younger subjects. The

Table 3. Results for Separate Age Groups Using the Wilcoxon Signed-Rank Test

	Present		Partly Present		Absent		Total Sites
	n	%	n	%	n	%	n
Sites after 6 Months (Ages 5-10)							
Delton	48	77	6	10	8	13	62
Ketac Silver	59	95	3	5	0	0	62
P < 0.005							
Sites after 6 Months (Ages 11-16)							
Delton	28	70	9	23	3	7	40
Ketac Silver	36	90	0	0	4	10	40
P < 0.2							
Sites after 12 Months (Ages 5-10)							
Delton	40	66	7	12	13	22	60
Ketac Silver	50	83	8	13	2	4	60
P < 0.01							
Sites after 12 Months (Ages 11-16)							
Delton	24	62	11	28	4	10	39
Ketac Silver	30	77	5	13	4	10	39
P < 0.2							
Sites after 24 Months (Ages 5-10)							
Delton	28	65	4	9	11	26	43
Ketac Silver	35	82	4	9	4	9	43
P < 0.05							
Sites after 24 Months (Ages 11-16)							
Delton	6	38	6	37	4	25	16
Ketac Silver	14	89	2	13	0	0	16
(Insufficient data for statistical test)							

reason for this is unclear. One possible hypothesis is that the adhesion of water-miscible cermet-ionomer cements to enamel may be compatible with the presence of small amounts of moisture, whereas adhesion of BIS-GMA resins is not.

Statistical exactness demands that only one pair of results be taken from each mouth. This is because two or more pairs of sealant results from one mouth would not strictly make them independent, one from the other. However, in this instance further statistical tests were undertaken using only one result from each mouth, and the outcome was found to be the same.

CONCLUSIONS

The results of this clinical trial showed that a cermet cement used as a fissure sealant gave superior results to a conventional resin sealant in young children between the ages of five and 10 years, where isolation is more difficult. In older children no significant difference in

Figure 1. *A Ketac Silver fissure sealant immediately after placement in a mandibular left permanent second molar*

Figure 2. *The same Ketac Silver fissure sealant as illustrated in Figure 1 after 12 months*

Figure 3. *The same Ketac Silver fissure sealant as illustrated in Figure 1 after 24 months*

Figure 4. *The same Ketac Silver fissure sealant as illustrated in Figure 1 after 48 months*

retention rates was observed between the two materials. Cermet-ionomer cements may find their ideal utilization in the placement of sealant restorations. Further trials are needed to confirm these findings over a longer period.

The clinical relevance of this study is that cermet-ionomer cement may prove a useful material in the future for sealing teeth in situations where ideal isolation is not achievable in young children or handicapped patients. It imparts some cariostatic benefit by leaching fluoride into contiguous enamel and dentin even if it should subsequently become detached, and its high compressive strength makes it suitable for small occlusal restorations that can be incorporated into an "all-in-one" sealant restoration.

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Effects of Design Features and Restorative Techniques on Marginal Leakage of MO Composites: an in Vitro Study

JON WILSON

Clinical Relevance
Attention to preparation design and to restorative technique may not be sufficient to prevent marginal leakage of MO composites.

SUMMARY

Effects of clinical practices on marginal leakage of MO composite restorations were studied in vitro. Three design scenarios and three restorative techniques were studied. A total of 45 premolars were used, providing five specimens for each of the nine design-technique permutations. The extent of marginal leakage was measured under magnification, after soaking the samples in a dye and then sectioning each sample mesiodistally. No significant differences were found between the permutation groups, although some clinical practices resulted in a lowered mean amount of marginal leakage.

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INTRODUCTION

The use of filled resins to restore posterior teeth has been questioned in recent years, with increased knowledge of the inferior in vivo performance of composites compared to amalgam (Gilbert, 1987; Lacy, 1987; Wilson, Mandradjieff & Brindock, 1990). A major concern is marginal leakage at the gingival wall (Lui & others, 1987; Ben-Amar, 1989).

In addition to choice of material systems, many other factors influence marginal leakage characteristics. Clinical variables have been studied by others (Cheung, 1990; Crim, 1991; Eakle & Ito, 1990; Saunders, Strang & Ahmad, 1990; Hinoura, Setcos & Phillips, 1988; Hansen, 1986; Lutz, Krejci & Oldenburg, 1986b; Vanherle & Smith, 1985; Ben-Amar & others, 1988); however, no data have been recently published that specifically investigate the combined effects of placement techniques and MO preparation designs on marginal leakage of premolars.

Design of the MO preparation can include a number of "anti-leakage" features. The author has proposed an axial wall groove, which provides a physical undercut to resist gap formation. Brännström, Mattsson, and Torstenson (1991) have suggested a different feature: a notch cut into the gingival wall using an atypical chisel may reduce gap formation by reducing the effects of flexure, deformation, creep, and flow.

Restorative technique can also be varied. Bulk packing is the quickest method. A second technique employs triangular increments and directional polymerization. A third alternative, based on correlations between adhesion and form described by Davidson (1986), uses thin rectangular increments to overcome the effects of polymerization shrinkage.

The objective of this investigation was to determine whether any combination of the above-mentioned design features and restorative techniques best minimizes marginal leakage of premolar MO composite restorations. The nine design-technique permutations were compared in vitro.

METHODS AND MATERIALS

Forty-five premolars were selected from an assortment of extracted teeth that had been stored in water. None of the selected teeth were cracked, restored, carious, or excessively worn.

Three configurations of cavity design features, diagrammed in Figure 1, were compared: an axial wall groove, a notch in the gingival wall, and a configuration with no added feature. Three restorative techniques, depicted in Figure 2, were simultaneously compared: bulk packing with occlusal polymerization, incremental/triangular with directional polymerization, and incremental/rectangular with occlusal polymerization.

The 45 premolars were each prepared for an MO composite restoration using a #245 bur in a high-speed handpiece with air cooling. The approximate height and width of each approximal box was 3.5 mm. The approximate depth of each approximal box was 1.2 mm, with each gingival wall containing both enamel and dentin. Each preparation was inspected for consistency and marginal integrity. Fifteen of the samples were further prepared with the addition of an axial wall groove. Using a 1/4 round bur in the high-speed handpiece with air cooling, this groove was placed along the entire axiogingival line angle to a depth of one half of the bur diameter. Fifteen other samples were further prepared with the addition of a notch in the

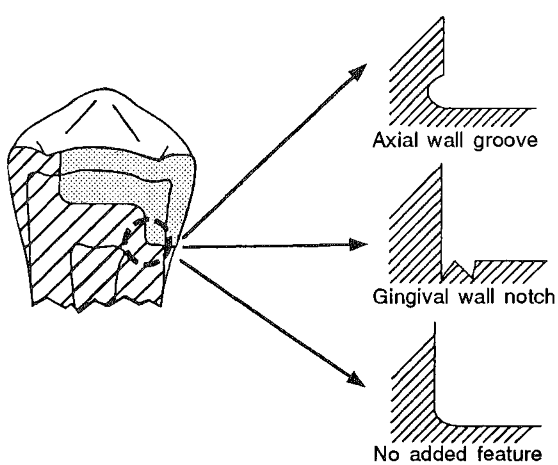

Figure 1. *Cavity design scenarios compared*

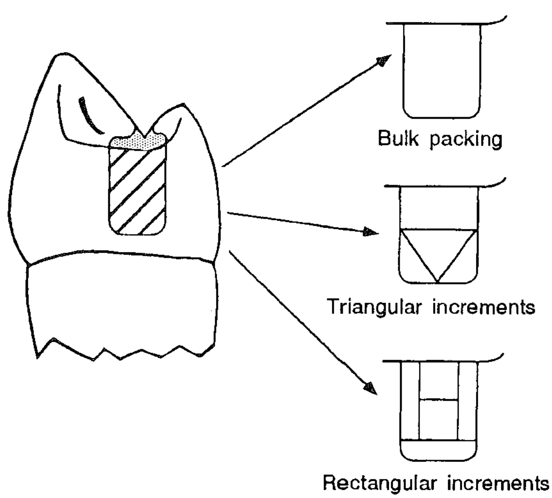

Figure 2. *Restorative techniques compared*

gingival wall using a prototype notched chisel (Dental Therapeutics AB, S-13145 Nacka, Sweden). Fifteen reciprocal strokes and firm hand pressure were used to place this groove along the entire axiogingival line angle. All 45 prepared premolars were stored in tap water to await restorative procedures.

Restorations were completed using the P-50 light-cure resin bonded ceramic with advanced particle coupling system (3M Dental Products, St Paul, MN 55144), following the manufacturer's directions. With the bulk packing procedure and the rectangular increments method, the polymerizing light source was directed from the occlusal. The triangular increments method used directional polymerization, with the light source directed from the buccal, then lingual, and finally from the occlusal aspect.

Restored samples were stored in tap water for seven days, then the margins were finished with medium cuttle and fine sand finishing disks (EC Moore, 13325 Leonard, Dearborn, MI 48126) to remove composite flash at the approximal box. Finished samples were soaked for seven days in methylene blue dye, then sectioned in a mesiodistal direction approximately along the centerline of each restoration.

The geometry of sectioned samples was measured using X30 power. The extent of marginal leakage was measured using X100 power. The data were analyzed using an analysis of variance (ANOVA), and a pairwise comparison was conducted using Duncan's multiple range test.

RESULTS

The mean extent of marginal leakage and the number of nonleaking samples for each of the nine test groups appear in Table 1. Grouped data for the three design features and for the three restorative techniques are also shown.

Using ANOVA, the influence of each of the design features on the extent of marginal leakage was analyzed. With 15 samples in each category, the effects were found to be not significant ($P > 0.05$).

ANOVA was also used to analyze the influence of each of the restorative techniques on the extent of marginal leakage (Table 2). With 15 samples in each category, the effects were

Table 1. Distribution of the 45 Premolars into Nine Test Groups

	Bulk Packing	Triangular Increments	Rectangular Increments
Axial Wall Groove	Group 1: #1, 12, 24, 32, 39	Group 2: #6, 16, 27, 28, 41	Group 3: #7, 15, 20, 35, 45
Gingival Wall Notch	Group 4: #2, 11, 22, 31, 37	Group 5: #5, 18, 25, 29, 42	Group 6: #9, 13, 19, 36, 43
No Added Feature	Group 7: #3, 10, 23, 33, 38	Group 8: #4, 17, 26, 30, 40	Group 9: #8, 14, 21, 34, 44

Table 2. Mean Extent of Marginal Leakage and the Number of Nonleaking Samples (shown in parentheses)

	Bulk Packing	Triangular Increments	Rectangular Increments	Grouped Data
Axial Wall Groove	1.13 mm (1)	0.89 mm (2)	1.87 mm (2)	1.30 mm (5)
Gingival Wall Notch	1.02 mm (0)	1.52 mm (1)	2.46 mm (1)	1.67 mm (2)
No Added Feature	1.90 mm (1)	1.31 mm (2)	1.45 mm (1)	1.56 mm (4)
Grouped Data	1.35 mm (2)	1.24 mm (5)	1.93 mm (4)	

found to be not significant ($P > 0.05$).

The nine design-technique combinations were also analyzed with ANOVA to compare the mean extents of marginal leakage. With five samples in each group, the combined effects of design and technique were found to be not significant ($P > 0.05$).

DISCUSSION

The three cavity design scenarios studied did not significantly influence marginal integrity. The axial wall groove provides a limited amount of undercut, a structural obstacle that unreliably resists gap formation. Consistent notches were not achieved with the prototype chisel; therefore, a correlation between altered creep/flow with gap formation could not be established.

None of the three restorative techniques studied could reliably prevent the formation of a marginal gap. Less extensive leakage with the triangular increments method can be attributed to directional polymerization, which enhances marginal integrity at the gingival wall. The comparable performance of bulk packing agreed with a similar study by Crim and Chapman (1986) and involved at least three phenomena: (1) without an approximal tooth, the transparent matrix yielded enhanced bonding at the gingival margin; (2) bulk packing resulted in higher internal condensation pressures; (3) bulk packing resulted in reduced cure at deeper areas, promoting flow and redistributing polymerization stresses. The relatively higher leakage associated with the rectangular increments technique could be attributed to circumferential disruption of adhesion, a phenomenon described by Davidson, de Gee, and Feilzer (1984). Marginal integrity might have been improved had the samples been directionally polymerized using laterally reflecting light wedges as recommended by Lutz and others (1986a).

The 45 MO composite restorations were created under standardized in vitro conditions using current materials. Even so, 76% of these samples exhibited marginal leakage. It can be expected that in vivo conditions such as dynamic loading, thermocycling, reduced access, and moisture will cause marginal leakage to be more severe.

CONCLUSIONS

This study did not establish any significant differences relating either (A) the type of design feature added or (B) the restorative technique to the extent of marginal leakage of in vitro MO composite premolar restorations. As a trend, the mean depth of marginal leakage was slightly less in those samples with the axial wall groove and those samples restored with either bulk packing or the triangular increments technique.

Constrained by limitations of currently available restorative materials, the design features and restorative techniques studied influenced, but could not reliably eliminate, marginal leakage of MO composite restorations.

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Fracture Strength and Fracture Patterns of Maxillary Premolars with Approximal Slot Cavities

O M EL-MOWAFY

Clinical Relevance
MO/DO slot amalgam restorations will minimize extent of cuspal fracture compared to conventional MOD amalgam restorations in maxillary premolars.

SUMMARY

The fracture strength and fracture patterns of maxillary premolar teeth prepared with two different cavity designs and tested with and without amalgam restorations were determined. No significant difference in the fracture strength of intact premolars and premolars prepared with conventional MOD cavities or slot MO/DO cavities was found whether or not the teeth were restored with amalgam. However, fracture pattern analysis revealed significant differences among the groups of teeth. Premolars with MO/DO slot cavities or slot amalgam restorations exhibited minimal fractures that involved enamel only in the majority of the cases. This behavior was similar to what was observed with intact premolars. In contrast, premolars with conventional MOD cavities or MOD amalgam restorations exhibited severe fractures that involved enamel, dentin, and the root in the majority of the cases. These severe fractures were statistically significantly different from those of premolars with slot cavities or slot restorations as well as from those of intact premolars. It is concluded that when maxillary premolars require restoration of carious lesions on both approximal sides without occlusal involvement, MO/DO slot amalgam restorations will be expected to

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result in teeth that are unlikely to undergo severe cuspal fracture compared to conventional MOD amalgam restorations.

INTRODUCTION

The subject of studying the strength of teeth following their preparation for restorative treatment is an important one, as it relates directly to their long-term longevity in the oral environment. Over the last decade or so, attention has been focused on this subject, and a number of studies appeared in the literature addressing the issue (Granath & Svensson, 1991; Zhou, Hu & Wang, 1989; Blaser & others 1983; Larson, Douglas & Geistfeld, 1981; Mondelli & others, 1980). Mondelli and others (1980), who examined the effect of varying the cavity width on the fracture strength of premolar teeth, found occlusal cavity preparations to decrease the strength of premolars in proportion to the width of the preparations. They also found that class 2 cavity preparations had a greater effect in weakening premolar teeth compared to class 1 cavities. Understandably, total separation of the facial and lingual cusps that takes place in class 2 cavities causes the teeth to fracture more easily compared to the partial separation that occurs in class 1 cavities. Blaser and others (1983) took the depth of the cavity into account and found deep MOD cavities to have a significantly greater weakening effect on premolar teeth compared to ideal-depth MOD cavities when the isthmus portion of the cavity was prepared wide. Granath and Svensson (1991), who studied the effect of cavity width and depth on displacement of facial and lingual cusps of premolar teeth during loading, found that the amount of cuspal displacement was directly related to the extent of cavity width and depth. An increase in cavity width and depth means an increase in cuspal displacement during loading and vice versa. A number of studies examining the strength of amalgam-restored teeth were also published during the last few years (Jagadish & Yogesh, 1990; Reeh, Douglas & Messer, 1989; El-Sherif & others, 1988; Watts, El-Mowafy, & Grant, 1987; Donly, Wild & Jensen, 1988). In general these studies agreed on one main principle, that amalgam-restored teeth were significantly weaker and less stiff than intact teeth, particularly when the test load was applied eccentrically on the triangular ridges of the cusps away from the amalgam restoration, i e, when the load was transmitted directly to the tooth structure and not indirectly through the restoration.

Although the above studies were basic laboratory investigations, there is no reason to underestimate their value in predicting long-term survival of restored teeth in the oral environment. Recently, in a retrospective clinical study published by Hansen, Asmussen, and Christiansen (1990) that looked back as far as 20 years at survival of amalgam-restored teeth, it was possible to see a direct correlation, to some extent, between the above laboratory findings and survival of restored teeth in the oral environment over this long period of time. The authors reported that posterior teeth with two-surface restorations had a markedly higher 20-year survival rate compared to posterior teeth with three-surface restorations, regardless if they were premolar or molar teeth. The survival period was defined as the time that elapsed since the tooth was restored and until cuspal fracture took place. Although the teeth in this clinical study were endodontically treated, the findings of the study can be applied in general terms to restored vital teeth. However, one would expect the frequency of cuspal fracture in restored vital teeth to be essentially less than in restored nonvital teeth.

In a clinical situation where there are carious lesions on both approximal surfaces of a posterior permanent tooth with the occlusal surface being free of caries, there are two possible cavity designs for the treatment of these lesions: a traditional design where an MOD preparation involving the whole occlusal surface is made, and a more conservative contemporary design where two separate "slot" prepartions (MO and DO) are made, leaving the noncarious central portion of the occlusal surface intact. The latter approach (slot preparation) was first referred to in the literature by Markley (1951). However, at that time Markley for some reason indicated that such a design could only be used in mandibular premolars where a box preparation can be made without an occlusal step. Twenty-two years later, Almquist, Cowan, and Lambert (1973) described the slot cavity in more detail and advocated its use in all posterior teeth with no exceptions. Typically, the candidate tooth has a moderate approximal lesion with no occlusal caries, and the fissure system on the occlusal surface is not defective. Osadetz (1977) also advocated the use of this cavity design for better conservation of healthy tooth structure.

The purpose of this investigation was to determine the fracture strength and fracture patterns of premolar teeth prepared with conservative approximal slot cavities, and compare them with those of similar premolar teeth prepared with conventional MOD cavities. This was expected to yield information that can help in predicting whether or not slot preparations may assist in prolonging the longevity of posterior teeth needing approximal restoration(s) compared to the conventional preparation.

METHODS AND MATERIALS

Forty extracted maxillary premolars were used in this study. These teeth were extracted intact due to orthodontical reasons and were stored initially following extraction in a solution of water and alcohol (75:25 ratio) for 24 hours for disinfection and then in water only for the rest of the experiment to prevent drying out. Using a micrometer, the dimensions of the crown portion of each tooth were measured in both the faciolingual (A) and mesiodistal (B) directions at the points of maximum contour. The two measurements were added up for each tooth, and the teeth were then divided into five equal groups in such a way so that the mean dimension (A + B) was similar in each group. This mean dimension ranged from 16.50 mm to 16.90 mm among the five groups. Also the ratio between first and second premolars was kept the same in all groups (six first premolars:two second premolars). Each tooth was then mounted in an acrylic resin base using a split aluminum mold in such a way so that the root of the tooth was totally embedded in the resin base except for the cervical 2 mm. The occlusal plane was aligned parallel to the horizontal plane. One group of teeth was selected at random at this stage and was stored in water in a refrigerator until further preparation. The remaining groups were assigned at random to two categories,each consisting of two groups. Teeth in the first category received moderate-size conventional MOD cavities prepared using tungsten carbide bur #245 under high speed with air/water spray for cooling. The bur was replaced with a new one after every two cavity preparations. The use of this bur resulted in producing cavities with rounded internal line angles. The width of the cavity was determined by first marking the cusp tips, which was achieved by gliding the occlusal surface of the tooth once on articulating paper supported on the bench. The occlusal cavity outline was then drawn in pencil, and it extended approximately 1/3 the distance between the cusp tips. The pulpal floor level was 0.5 mm into dentin. Approximally, the cavity gingival margin was placed 1.5 - 2.0 mm above the cervical line, and the axial wall depth was 0.5 mm into dentin. The facial and lingual walls in both the occlusal and the approximal portions of the preparation were slightly converging towards the occlusal surface. Retention grooves were placed in the approximal boxes using a quarter-round steel bur running at low speed. The grooves started at the axiogingivofacial and axiogingivolingual point angles, extended along the axiofacial and axiolingual line angles, and terminated at the pulpal floor level. One of these two groups was stored in water in the refrigerator at this stage and until further preparation. Following standard techniques, teeth of the other group were restored with a high-copper amalgam (Tytin, Kerr Manufacturing Company, Romulus, MI 48174). Teeth of the other category received two separate MO and DO slot cavities using the same size bur. Occlusally, the outline of each cavity was rectangular in shape and extended just beyond the boundaries of the triangular fossa but short of the triangular cusp ridges. Approximally, the gingival margin of the cavity was placed 1.5 - 2.0 mm above the cervical line, and the axial wall finished 0.5 mm into dentin. The facial and lingual walls were prepared so that they were slightly converging towards the occlusal surface. Two retention grooves were placed in each slot preparation at the same locations and in the same manner as for the teeth prepared with MOD cavities. According to Crockett and others (1975), retention grooves are the only means of retention against approximal displacement in the slot preparation. One group of these teeth was stored in water in the refrigerator at this stage until further preparation, while teeth of the other group were restored with the above amalgam material in the same manner as the group of teeth with MOD restorations.

Teeth in all the groups were then remounted in another acrylic base in such a way so that the occlusal plane was inclined lingually at approximately 45° to the horizontal. This was achieved by first trimming the original resin base at the bottom at a 45° angle using a bench trimmer. The base of the tooth was then reimbedded in a larger resin base using a larger size steel ring. As a result, the occlusal surface of the tooth was now inclined lingually 45° to the horizontal and the tooth supported by the resin base. Following preparation, all groups of teeth were stored in water at 37 °C for 24 hours prior to mechanical testing.

Using a specially made loading steel device, each tooth was subjected to uniaxial compressive loading in a Universal Testing Machine (Instron Corporation, Canton, MA 02021). The load was applied by means of a steel rod with a rounded thin end 2.50 mm in diameter (Figures 1 & 2). This touched the lingual cusp at a point approximately midway along the triangular ridge. In the case of the teeth with MOD preparations, the edge of the loading rod was kept away from the cavity margin and remained on the cuspal triangular ridge during loading. Because the tooth was positioned at 45° to the horizontal, the applied load concentrated mainly on the lingual cusp. Similar loading methods were reported previously in the literature (Reagan, Schwandt & Duncanson, 1989; Fissore, Nicholls & Yuodelis, 1991). The rate of loading

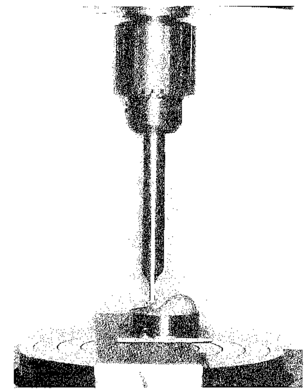

Figure 1. *Premolar tooth mounted on the mechanical test assembly on the Instron testing machine*

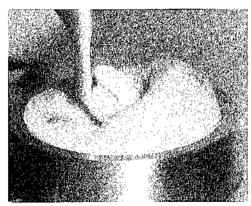

Figure 2. *Close-up of a premolar tooth with two approximal slot cavities being subjected to compressive loading. The steel loading rod contacted the lingual cusp at a central point along the triangular cusp ridge.*

was 1 mm/minute, and loading continued until fracture of part or of the whole lingual cusp took place. Fracture load was recorded in Kg, and the tooth was examined under magnification to determine the severity or pattern of the cuspal fracture. The mean fracture loads were calculated for each group. Following recommendations made by Alpher and Presswood (1991) for similar investigations, fracture strength data were analyzed statistically using Dunnett's multiple comparison test and one-way analysis of variance. Fracture pattern data were analyzed statistically using Fisher's two-tail exact test.

RESULTS

Table 1 shows mean fracture strength values for teeth of the test groups. Fracture strength value was found to be independent of the dimensions of the tooth. The statistical analysis showed no significant difference in the mean fracture strength values among the five groups either when the mean load values were analyzed or when the mean (load/A+B) values were analyzed (P = 0.057).

Table 2 shows the distribution of the fracture patterns of the teeth among the tested groups. Generally more severe fracture patterns (involving enamel and dentin or enamel, dentin, and the root in 81% of the cases) occurred in the groups of teeth with MOD preparations and MOD amalgam restorations. For the groups of MO/DO slot preparations and MO/DO slot amalgam restorations, the fractures were generally less severe (involving enamel only in 75% of the cases) and were comparable to those of the intact teeth group, which involved enamel only also in 75% of the cases. Statistical analysis showed significant differences in fracture patterns among the groups (P = 0.0062). Further pairwise analysis showed significant differences between the intact teeth group and the groups with MOD preparations and MOD amalgam restorations (P = 0.008 and 0.032 respectively). Significant differences were also found between the group with MOD preparations and the group with MO/DO preparations (P = 0.010) and between the group with MOD amalgam restorations and the group with MO/DO preparations (P = 0.040).

Figures 3 through 7 show pictures of representative fractured teeth from the five test groups.

DISCUSSION

In the present study, there were no significant differences between the fracture loads of the five test groups. However, the extent and pattern of fractures are significantly different. Maxillary premolars with MO/DO slot preparations or with MO/DO slot amalgam restorations fractured in the same manner as did intact premolars. The size and extent of the fractures were similar in the three groups and were minimal (involving enamel only) in 75% of the cases. However, for premolars with MOD cavities or with MOD amalgam restorations, fractures were large and extensive, involving enamel and dentin or enamel and dentin as well as root structure in 81% of the cases. This is important in the clinical situation: when maxillary premolars with MOD amalgam restorations undergo cuspal fracture, a picture similar to the one shown in Figure 6 is usually seen, and the tooth may or may not be restorable depending on the level of the fracture line. If the fracture

Table 1. Mean Fracture Load for Each Group of Teeth

Group	Mean Fracture Load in Kg	Mean Fracture Load Kg/ (A+B)* mm
Intact premolars	39.0 (8.9)	2.33 (0.46)
Premolars with MOD preparations	34.5 (8.8)	2.16 (0.53)
Premolars with MO/DO preparations	47.3 (10.1)	2.83 (0.52)
Premolars with MOD restorations	38.3 (9.8)	2.32 (0.52)
Premolars with MO/DO restorations	38.4 (7.5)	2.28 (0.55)

Table 2. Distribution of Cuspal Fracture Type

	Fracture Involves		
Group	Enamel Only	Enamel and Dentin	Enamel, Dentin, and Root
Intact premolars	6	2	0
Premolars with MOD preparations	1	1	6
Premolars with MO/DO preparations	7	0	1
Premolars with MOD restorations	2	1	5
Premolars with MO/DO restorations	5	1	2

Figure 3. *Intact premolar tooth following mechanical testing. Only a moderate amount of fracture took place.*

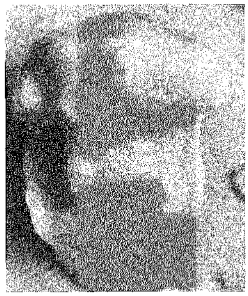

Figure 4. *Premolar tooth with an MOD cavity following mechanical testing. The whole lingual cusp fractured off in this case.*

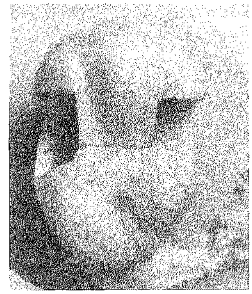

Figure 5. *Premolar tooth with MO/DO approximal slot cavities following mechanical testing. Minimal fracture involving enamel only took place in this case.*

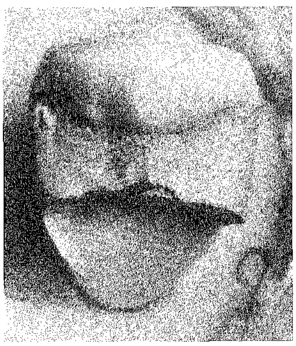

Figure 6. *Premolar tooth with an MOD amalgam restoration following mechanical testing. The whole lingual cusp fractured off in exactly the same manner as with the unrestored tooth shown in Figure 4.*

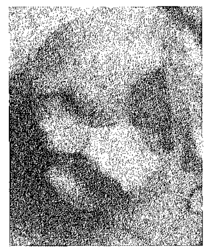

Figure 7. *Premolar tooth with MO/DO approximal slot amalgam restorations following mechanical testing. Minimal to moderate fracture of the lingual cusp took place similar to that of the intact tooth shown in Figure 3 and of the tooth with the MO/DO approximal slot cavities shown in Figure 5.*

line extends beyond the level of the attached gingiva, then periodontal surgery might be indicated in order to render the tooth suitable for restoration. If the fracture line was even farther apically, the tooth might not be restorable. On the other hand, there is indication based on the present findings that if maxillary premolars with MO/DO slot amalgam restorations were to undergo cuspal fracture, the teeth would be most likely readily restorable due to the possible limited extent of the fracture in the majority of the cases.

Although the present study is an in vitro one, the findings can be correlated to the clinical situation to some extent. In the oral environment intact premolars do not undergo cuspal fracture under normal masticatory forces. However, in maxillary premolars with MOD amalgam restorations, cuspal fractures do occur, but under another loading mechanism different from that of the laboratory test. Masticatory force application results in stress concentration along the pulpolingual and pulpofacial line angles of the restored cavity. Under repeated loading and unloading these stresses can result, on the long term, possibly over a number of years, in cuspal fatigue with subsequent cuspal fracture. The teeth in the present study were fractured under one direct loading process without fatiguing. However, the general fracture pattern of premolars with MOD cavities or MOD amalgam restorations observed in the present study is very similar to fracture patterns exhibited clinically by maxillary premolars with MOD amalgam restorations. As a result one can see that the findings of the present study are applicable to the clinical situation. Thus, it can be concluded that maxillary premolars with approximal slot amalgam restorations will be expected to result in less cuspal damage should cuspal fracture take place in the mouth, compared to premolars with MOD amalgam restorations. Furthermore, Sturdevant and others (1987), who studied several cavity designs for class 2 amalgam restorations, reported that higher loads were required for amalgam restoration failure when they compared the approximal slot design to designs with occlusal dovetail. This means that not only the tooth with the approximal slot restoration will be less vulnerable to severe cuspal fracture, but also the amalgam restoration itself will be stronger than the one with an occlusal dovetail, as it does not have an isthmus.

CONCLUSION

It is interesting to note in O'Hara and Clark's survey (1984) of all dental schools in the United States, Canada, and Puerto Rico that only 68% of these schools teach the approximal slot amalgam restoration. Findings in the present study clearly indicate the superiority of the approximal slot amalgam restoration over the conventional approximal/occlusal amalgam restoration in terms of minimizing the amount of lost tooth structure should fracture of the restored tooth take place. It is the view of the author of this study that approximal slot amalgam restorations should be taught in dental schools routinely and used by dentists whenever there is an indication for their use.

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DEPARTMENTS

Abstracts

An *in vitro* comparative analysis: scanning electron microscopy of dentin/restoration interfaces. *Youngson CC & Grey NJA (1992) *Dental Materials* 8 252-258.

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The purpose of this study was to investigate the nature of the in vitro interface between dentin and various restorative systems that claim to bond to dentin. There appears to be an accumulating body of evidence that suggests that bonding systems that retain the smear layer are preferable: they show the least dye penetration into dentin. Almost all interface morphologies could be interpreted as showing some evidence of mechanical bonding to dentin; no conclusions regarding the nature of a chemical bond could be inferred. The only material combination that consistently showed very large gap formations and exposed dentinal tubules was a group restored without the benefit of a bonding system or adhesive base material.

None of the studied bonding systems provides a complete hermetic seal between composite and dentin. Bonding systems that remove the smear layer tended to show more adhesive failures at the bonding system/dentin interface. Some retention of composite may be gained by the presence of resin "pulls" between the composite and bonding resin/dentin interface. Several interface morphologies can be found under a restoration, implying that localized contamination of the bonding system/dentin and bonding system/composite interface can occur even in the most favorable laboratory conditions. The study should be repeated in vivo to determine the effect the placing of the bonding systems in the presence of tubular outflow has upon the resultant interface morphologies.

The influence of surface conditions and silane agents on the bond of resin to dental porcelain. *Hayakawa T, Horie K, Aida M, Kanaya T & Murata Y (1992) *Dental Materials* 8 238-240.

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The influence of the porcelain surface condition and the application of silane agents on the adhesion between resin and dental porcelain was investigated. Three commercially available silane agents were applied to three different kinds of porcelain surfaces. The bond strength of light-cured composite to dental porcelain was measured by use of shear force according to Noguchi's Method. The three porcelain surfaces were 1) polished with #1000 SiC paper, 2) etched with phosphoric acid gel for 60 seconds after #1000 polishing, or 3) etched with hydrofluoric acid gel for 60 seconds after #1000 polishing. Data were tested for significant differences using ANOVA and Scheffé's tests. Surfaces were examined using SEM. Of the specimens prepared without silane coupling agents, those specimens etched with hydrofluoric acid produced the highest bond strengths. The combination of hydrofluoric acid etching and an application of Cosmotech Porcelain Primer (CPP) increased the bond strengths more than that of phosphoric acid etching. With the application of Laminabond Porcelain Primer (LPP) or Optec Silane Coupling Agent (OSCA), high bond strengths were obtained regardless of the porcelain surface condition. Although the detailed components of silane agents are unknown, LPP and OSCA were thought to be in an activated state to react with the OH groups on the porcelain surface, forming siloxane bonds. CPP only improved the wettability of composite to porcelain. Hydrofluoric acid etching is not needed to obtain strong adhesion between composite and porcelain if silane agents, which react with the OH groups on the porcelain surface, are used.

Secondary caries in situ around fluoride-releasing light-curing composites: a quantitative model investigation on four materials with a fluoride content between 0 and 26 vol %. *Dijkman GEHM & Arends J (1992) *Caries Research* 26 351-357.

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This study was designed to measure the effects of three different fluoride-releasing composites against a nonfluoridated control with regard to mineral loss and lesion formation in enamel within and around an artificially created marginal gap.

Several previous studies have shown recurrent caries to be a major factor necessitating replacement of composite restorations. Significant marginal discrepancies with attendant microleakage have been reported in 50% or more of all types of composites. Although fluoride has been added to several composite systems, aiming to reduce caries susceptibility, studies have not shown the mechanism of any caries-preventive effects. It is not known whether the lack of recurrent caries noted at the margins of fluoride-releasing restorations results from fluoride in the fluid of the marginal gap or from fluoride taken up by the surrounding surface enamel.

In this study, completed in the Netherlands, extracted human enamel samples were prepared and restored with three different light-cured fluoride-releasing composites. The samples were luted to complete denture bases in a manner to accumulate plaque and were worn for a month. A 200-micron marginal gap was created at the composite-enamel interface, and enamel mineral content was read at three points on the exposed surface adjacent to the composite and at three levels within the gap.

Enamel demineralization was more extensive near the nonfluoridated composite than the others. The reduction in mineral loss and lesion depth was less in the two high-fluoride products than in the lower one. The effect within the gap was substantially greater than in the adjacent smooth outer surface. Results indicated that maximum effect of fluoride levels off at 9% volume.

This study would indicate that fluoride-containing composites can now be added to silicates and glass ionomers as restorative materials with caries-inhibiting potential.

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