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

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GUEST EDITORIAL

Standards of Excellence

When Bill von der Lehr took me to my first Academy meeting in 1985, I immediately felt that this organization was different. From the beginning, the Academy of Operative Dentistry has been my most valuable and treasured membership. We are a unique mixture of private practitioners and academicians. Membership requires no political stature or position, only an interest in excellence in operative dentistry. The annual meetings have always been excellent, and there is a comfortable fellowship among our members that exists in no other organization of which I have been a member.

During my years as a member of this Academy, many positive changes have occurred. We have resisted the attempts by dental education to relegate operative dentistry to an inferior and unimportant role. The American Board of Operative Dentistry continues to flourish with members being added each year. We have added a European Section, which gives us true international status. Our move to the Fairmont Hotel has greatly enhanced our annual meeting with improved and expanded facilities.

Since the founding of this Academy, there have been dramatic changes in dentistry. Dental disease patterns have been dramatically altered by fluoridation and patient education in oral hygiene. Dental care standards have followed suit with ever-evolving methods of preventive care and conservative treatment. During any era of rapid change, there is both good and bad. This Academy has stood for excellence throughout these changes, and I am confident will continue to do so in the future.

As we rushed into the era of acid-etched bonding and composite resin dentistry, clinicians in this Academy cautioned us not to be in such a hurry to abandon the proven techniques for hype and sensationalism. We have seen this journal become one of the most respected scientific publications as these new materials and techniques have been improved and researched by sound, scientific methods. We have invited the leading scientists and clinicians to present at our annual meeting, and this Academy has steadfastly resisted attempts to commercialize our meetings and our journal.

If I have observed one disturbing trend in dentistry, it is the unwillingness of our colleagues to read scientific literature and become critical thinkers. I have heard lecturers who proclaim themselves as "clinicians, not scientists" get applause from an audience when they make fun of scientific research. Industry publications that are supported by advertising dollars are the most read and believed literature. Sales people regale doctors at meetings with extravagant and unproven claims about new materials and techniques. We have all wasted countless dollars and time on stuff that proved to be worthless because we believed a self-proclaimed expert rather than a careful researcher. The most eloquent speaker is not necessarily the most knowledgeable. Research and good, practical clinical dentistry are not mutually exclusive. Sound science and careful clinical research take some time, but in the end our patients are better served and that, after all, is what should be our ultimate goal.

I urge the members of this Academy to never depart from their standard of excellence and to always promote the highest level of patient care.

EBB A BERRY, III
President
Academy of Operative Dentistry

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ORIGINAL ARTICLES

Sealing and Dentin Bond Strengths of Adhesive Systems

M O DEL NERO • J C DE LA MACORRA

Clinical Relevance
A perfect seal to water seems impossible with current adhesive materials.

SUMMARY

The objectives of this research were (1) to analyze the variations of the permeability of dentin after restoration with two polyacid-modified resin composites (Compoglass, Dyract) and four single-bottle adhesives (Prime & Bond 2.0, Syntac Single Component, OptiBond Solo, and Single Bond—Scotch Bond 1 in Europe—immediately (approximately 1 hour) after insertion. A perfusion system with distilled water was used at a pressure of 32.5 cm of water; (2) to study the bond strength of their interfaces; and (3) to find the correlation, if any, between both parameters. None of the materials used produced a complete cessation in fluid filtration. Tensile bond strengths were very low (maximum: P&B = 3.96 MPa) probably because of the very large bonding surfaces used (mean bonded surface area = 88.8mm²). No significant correlation was found between tensile bond strength and the sealing ability for any material.

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INTRODUCTION

The production of a perfect seal on the material-tooth interface is one of the goals of restorative dentistry in order to prevent the entrance of microorganisms and other contaminants into the environment as well as to reproduce the lost peripheral seal of dentin.

Dentin bonding agents (DBAs) are designed to produce a hermetic seal by their intimate relationship with the cut dental tissues, properly prepared, forming what is called the hybrid layer. A proper seal is required to provide clinically acceptable hydrodynamic behavior of dentinal fluid (Pashley, 1994).

Loss of dental tissues by caries or their elimination by cavity preparation tends to increase the permeability of the remaining dentin (Fogel, Marshall & Pashley, 1988; Linden, Kallsog & Wolgast, 1995).

This increase in permeability is less noticeable in coronal dentin if the smear layer is present, but becomes more noticeable in the vicinity of the pulp chamber (Tagami, Tao & Pashley, 1990). From this point of view, an ideal material would be one that lowers dentin permeability to previous levels of intact tooth (Pashley & others, 1988), regardless of the amount of remaining dentin.

Usually, the methodology employed to study the peripheral seal of the dentin-pulp complex utilizes morphological or microleakage studies in vitro or clinical studies that measure dentin sensitivity to thermal or osmotic stimuli in vivo. None of these studies takes into account the previous permeability conditions of dentin. All use subjective measuring systems such as the analogue scales for pain estimation, allow the study of only small areas of the restored interface (morphological studies), or examine microleakage using dyes. However, dyes are not normally in contact with dentin, and have different chemical and physical characteristics from the substances that would normally pass through such interfaces.

Derkson, Pashley, and Derkson (1986) described an in vitro system to measure the efficacy of sealing the dentin-pulp complex by quantification of dentinal permeability before and after obturation with different materials. This permeability is expressed by measuring the amount of fluid that comes through the area studied per unit time. This method has been used in numerous studies to determine the sealing efficacy of many materials (Pashley & others, 1985; Pashley & Depew, 1986; Del Nero, Conejo & de la Macorra, 1994, 1997; Prati & others, 1992, 1994a; Hansen, Swift & Krell, 1993; Pagliarini & others, 1996; Déjou, Sindres & Camps, 1996). A common observation in such studies was that the filtration through dentin slowed but did not stop with any of the materials studied. Similar results were found with other measuring systems based on the same idea (Terkla & others, 1987). That is, most materials do not perfectly seal immediately, although the seal improves with time in some cases.

On the other hand, there have been attempts to correlate the sealing ability of materials with the mechanical resistance of the interface they produce. There are reports about the relationship between various DBAs on different kinds of dentin (superficial, intermediate, and deep) in vivo (Pashley & others, 1993) and in vitro (McCabe & Rusby, 1992). The deepest dentin was associated with higher permeability, although the changes were not controlled. Prati and others (1994b) measured the changes in hydraulic conductivity of dentin when different DBAs were applied, but the changes in the permeability after obturation with the corresponding composite resin were not reported. Many other reports have been published about the mechanical characteristics of bonded interfaces in simulated (Mitchem, Terkla & Gronas, 1988; Prati, Pashley & Montanari, 1991; Davidson, Abdalla & de Gee, 1993; Paul & Scharer, 1994; Nikaido & others, 1995; Mitchem & Gronas, 1991; Gerhardt, Szep & Heideman, 1995; Krejci & others, 1994) or real (Pashley & others, 1993) physiological conditions, but, at the moment, the correlation between the sealing ability and the bond strength of the new polyacid-modified composite resins or the monocomponent DBAs has not been studied.

The objectives of this paper were to analyze the variations of the permeability of dentin after sealing with different materials immediately after insertion, to study the bond strength of their interfaces, and to find the correlation, if any, between both parameters.

METHODS AND MATERIALS

Surgically extracted sound third molars had their roots removed with a diamond disk, exposing the pulp chamber. The soft tissue was removed with cotton pliers, taking care not to touch the chamber

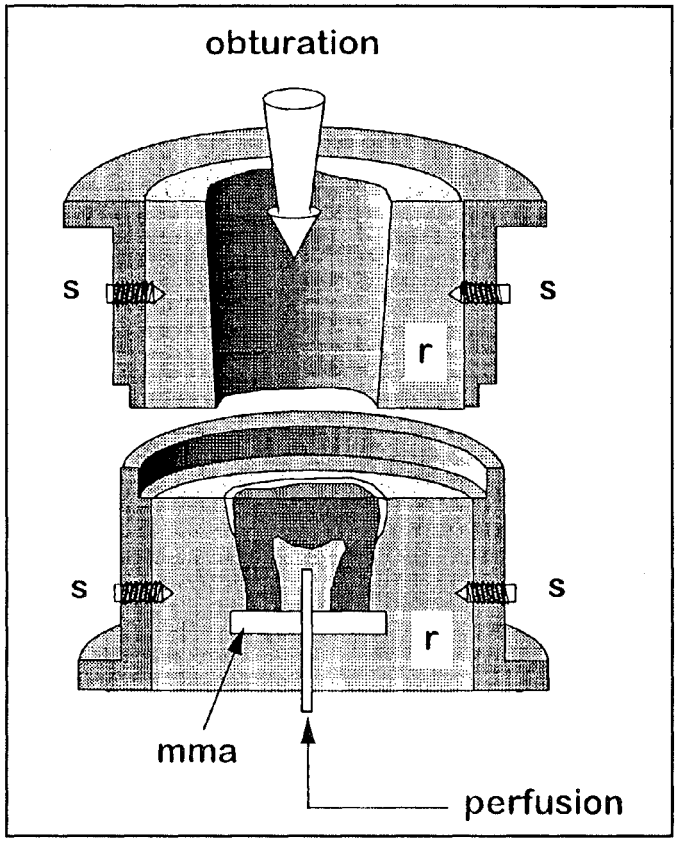

Figure 1. *Schematic hemisection of setup. mma = methylmethacrylate base; r = embedding resin; s = fixing, embedded screws. Obturation is made through upper matrix (white arrow) when the device is assembled.*

roof. With a commercial cyanoacrylate glue (Super Glue 3, Loctite, Madrid, Spain), a rectangular piece of methacrylate with a hole in its center was attached to the radicular portion of the crown segment (Figure 1). A metal tube was passed and sealed through a hole in the plexiglass, allowing the perfusion of each specimen. Occlusal enamel was ground away using 120-grit paper (Struers, Rodovre, Copenhagen, Denmark), thus exposing as much dentin as possible. The dentin and enamel areas were measured in each specimen with an image analyzer (VIDS IV, AMS, London, England, UK). This surface was finished with 600-grit paper. The specimens were embedded in a cylindrical device with a polyester resin (Cronolita 10700 + Activator 3015, Plastiform SA, Madrid, Spain). In the upper part of the assembly, a resin matrix was fabricated to confine the restorative materials. Through this matrix the restorative materials were inserted, once both sections of the assembly were properly positioned (Figure 1).

The teeth were connected to a perfusion system, at a pressure of 32.5 cm of distilled water through the metal tube into the pulp chamber. A 100±1 µL graduated micropipette was inserted between the tooth and the pressure reservoir. Once the system was stable, an air bubble was placed in the micropipette with the help of a microsyringe. The movement of this bubble permitted measurement of the fluid volume lost from the system through the cut dentin surface.

The fluid flow through each specimen was measured in µl/min for 30 minutes (preinsertion period), with readings approximately every 5 minutes. After this, the cut dentin surfaces were obturated through the resin matrix with the DBA and the restorative material, and the fluid flux was measured during a postinsertion period between 60 and 120 minutes, reading in a similar fashion as in the preinsertion period.

Each material was prepared following the manufacturer's instructions and placed in at least three increments, curing each one for 40 seconds (Translux C L, Kulzer, Wehrheim, Germany). Materials tested were: Compoglass (COM) with SCA, Tetric with Syntac SC (SYN) (Ivoclar/Vivadent, Schaan, Liechtenstein), Dyract with PSA (DYR), TPH Spectrum with Prime & Bond 2.0 (P&B) (DeTrey/Dentsply, Konstanz, Germany), Z100 with Scotch Bond 1—named Single Bond in USA—(SB1) (3M Dental Products, St Paul, MN 55144) and Prodigy with OptiBond Solo (OPT) (Sybron/Kerr, Romulus, MI 48174).

In some materials (P&B, SYN, OPT, SB1) two parts of the postinsertion curve were defined (Figure 2). The first part was the first 30 minutes postinsertion; this part of the curve followed a logarithmic decline. Its slope was not considered in the calculations of the final fluid flow decreased, because it corresponded to the rehydration of the teeth following etching and air drying. Its slope is referred to in the text, results, and tables as the *immediate decrease*. The second part was linear, and calculations of the decrease in fluid flux (*final decrease*) were made using its slope.

In any period, the slope of the regression line of the data volume (µl) to data of time (minutes) was used as the parameter defining the fluid filtration.

Once the postobturation time had passed (120 minutes), tensile force was exerted over the entire restored surface (enamel and dentin) at a crosshead speed of 1 mm/min (H 5000M/79L, Houndsfield Test Equipments, Croydon, England, UK), in the direction perpendicular to the bonded surfaces.

There are some reports (Roderer & others, 1995; Fowler & others, 1992; Burrow & others, 1994) that measured the bond strength of several materials to enamel and dentin under the same conditions. The pooled ratio of enamel tensile bond strength to that of dentin was found to be 2.003. This relationship was taken into account in our calculations to assign the corresponding bond strength of resins to the different dental tissues.

ANOVA and Newman-Keuls tests were carried out to find if there were statistically significant differences among the results for each material on final fluid flow decrease and on tensile bond strengths (TBS).

Regression correlation of decrease in fluid flow versus TBS was calculated for P&B, SYN, DYR, and COM.

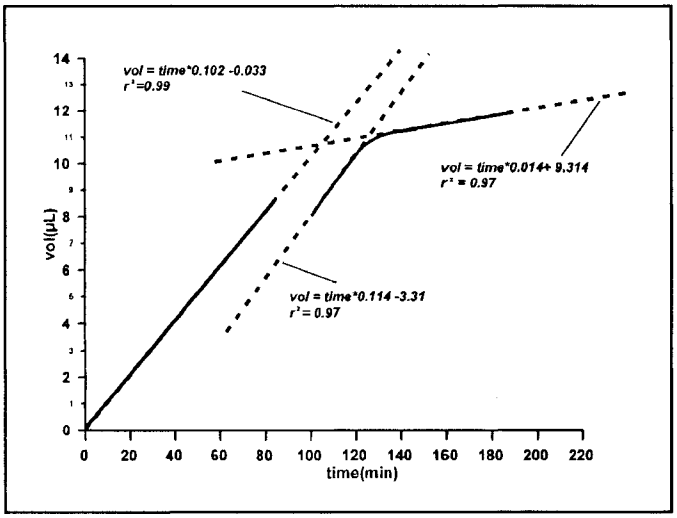

Figure 2. *Plotting of one sample of SB1, showing preinsertion, immediate, and final parts of postinsertion periods. The break in the line was due to the time of insertion of the material; note the slow decrease in fluid flow over 30 minutes postinsertion, until it reached a constant slope.*

Table 1. Reductions in Fluid Flow across Dentin Produced by Various Restorative Materials

		IMMEDIATE (0-120 minutes)			FINAL (30-120 minutes postinsertion)		
Material	n	Mean	SD	SE	Mean	SD	SE
COM	17	77.50	10.47	2.63	---	---	---
DYR	16	73.70	12.29	3.34	---	---	---
SYN	14	75.84	8.11	---	86.00	5.50	1.79
P&B	24	73.66	15.51	---	81.06	15.60	2.56
SB1	18	81.00	16.06	---	88.57	10.97	2.56
OPT	16	72.14	17.24	---	83.39	13.69	3.72

Values are percent reductions from the nonrestored values. A theoretically perfect seal would produce a 100% reduction in fluid flow.
COM = Compoglass with SCA; DYR = Dyract with PSA; SYN = Tetric with Syntac SC; P&B = TPH Spectrum with Prime & Bond 2.0; SB1 = Z100 with Scotchbond 1 (Single Bond); OPT = Prodigy with OptiBond Solo; n = number of specimens; SD = standard deviation; SE = standard error ($P < 0.001$). Mean ± SE ($P < 0.001$): Limits for % reduction in postinsertion fluid flow relative to preinsertion values with 99.9% confidence.

RESULTS

The Kolmogrov-Smirnof one-sample test was used to measure the amount by which the empirical cumulative distribution function differed from that of the filled distribution. No significance was found. The ANOVA and Newman-Keuls tests were employed to look for differences in the mean values of continuous quantitative variables.

Table 1 shows reductions in fluid flow across dentin produced by the restorative materials. Values are given as percent reductions from the nonrestored values in the various treatment groups, in the immediate and final postinsertion periods. ANOVA testing showed that there were statistically significant differences among the materials ($P < 0.05$). The Newman-Keuls test determined that the difference was: SB1 > DYR ($P < 0.01$) in the immediate group, with all other materials not statistically different.

Table 2 summarizes the TBS data (MPa) for the whole surface and that corresponding to dentin (details given below). ANOVA testing showed that there were statistically significant differences among the materials ($P < 0.01$). The Newman-Keuls test determined the differences were: P&B > DYR ($P < 0.001$), P&B > COM ($P < 0.01$), and P&B > SYN ($P < 0.05$).

Figures 3-6 show the plots of the decrease in final fluid flow versus total tensile bond strength with each regression line. In all cases, the correlation between fluid flow decrease and tensile bond strength was very low and statistically insignificant.

DISCUSSION

Fluid Flow Decrease (FFD)

There are many reports of variations in dentin permeability due to the interaction with different restorative materials or DBAs (Pashley & others, 1985; Pashley & Depew, 1986; Del Nero & others, 1994, 1997; Prati & others, 1992, 1994a; Hansen & others, 1993; Pagliarini & others, 1996; Déjou & others, 1996). In these reports, larger decreases in permeability occurred when the smear layer was eliminated. In the studies where smear layer was not removed, the percentage of permeability decrease was smaller, although many of the materials tested required some kind of etching. One explanation could be that the baseline was more unfavorable if the dentin was etched, because this procedure increased permeability. None of the published studies reports the creation of a perfect seal (i e, 100% decrease in fluid flow). Our work was in accordance with those previously published reports. Our results indicated a wide range in the decrease in permeability, which was highly variable, depending on the kind of material and the type of specimen used. Nevertheless, our results were in accordance with those of Terkla and others (1987), who used a similar tooth preparation.

Table 2. Dentin and Total Tensile Bond Strengths of the Various Restorative Materials (MPa)

		Dentin		Total		
Material	n	Mean	SD	Mean	SD	SE
COM	14	1.74	0.75	2.39	1.08	0.35
DYR	12	1.22	0.46	1.64	0.62	0.25
SYN	9	2.06	0.90	2.72	1.22	0.77
P&B	8	2.97	0.97	3.96	1.24	0.96

n = number of specimens; SD = standard deviation; SE = standard error ($P < 0.001$). Mean ± SE ($P < 0.001$): Limits for tensile bond strengths with 99.9% confidence.

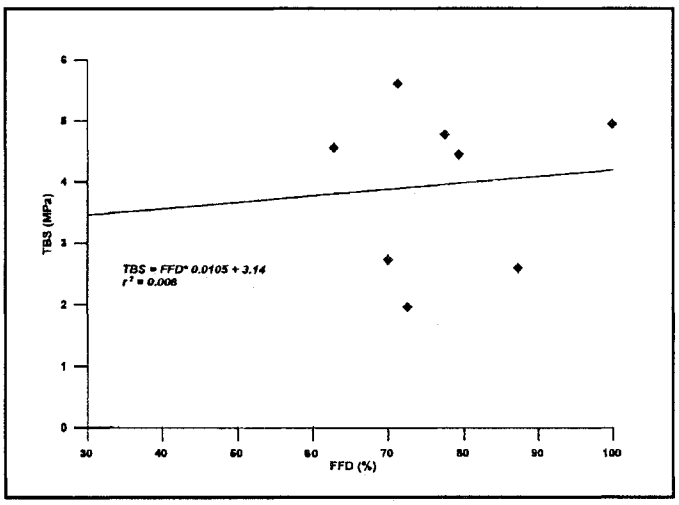

Figure 3. *Plot of final decrease of permeability (FFD) versus total bond strength (TBS) for P&B*

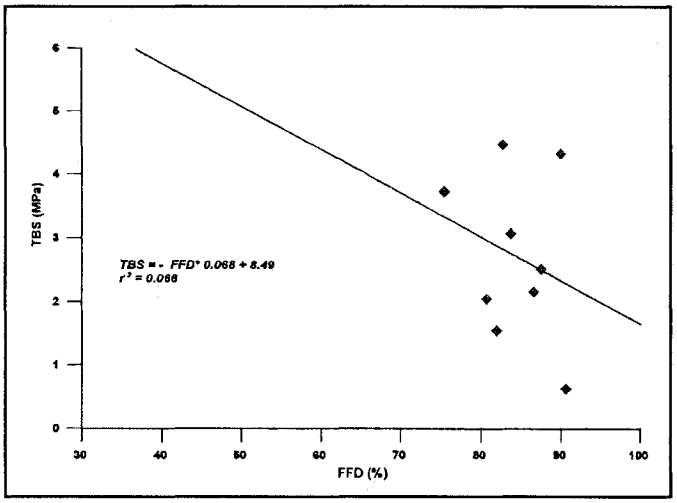

Figure 4. *Plot of final decrease of permeability (FFD) versus total bond strength (TBS) for SYN*

With our methodology it was not possible to reconcile the persistence of fluid perfusion after insertion of restorations with the very good clinical behavior of these materials (Pashley & Carvalho, 1997; Nicholson & Croll, 1997; Van Meerbeek & others, 1998). Generally, the quality of the interface between teeth and restorative materials has been studied using the leakage of dyes. However, the absence of dyes or, to be more precise, the lack of their detection, does not necessarily mean that the interface is hermetically sealed to water, which has a molecular weight of 18, as opposed to the much higher molecular weights of currently used dyes (ca 200-300; Pashley, 1997).

In our experimental design, the residual permeability of restorations may be due to fluid loss through the unsealed dental surfaces. In our experience, applying nail varnish to such surfaces reduces specimen permeability to a minimum percentage (unpublished data), but not to zero. It has to be remembered that when using dentin disks (Pashley & others, 1985; Hansen & others, 1993; Del Nero & others, 1997) the expected 100% seal may not be obtained, possibly due to fluid leakage across the lateral surfaces of the disks.

The behavior of the fluid flux seems to have different patterns depending on the material studied. For COM and DYR (both polyacid-modified resins) the pattern seemed to be strictly linear. For the other materials (P&B, SYN, OPT, SB1), which require total etch, it seemed to have two different patterns. The first part of the plotting may represent the rehydration of the dentin from the pulp chamber, and

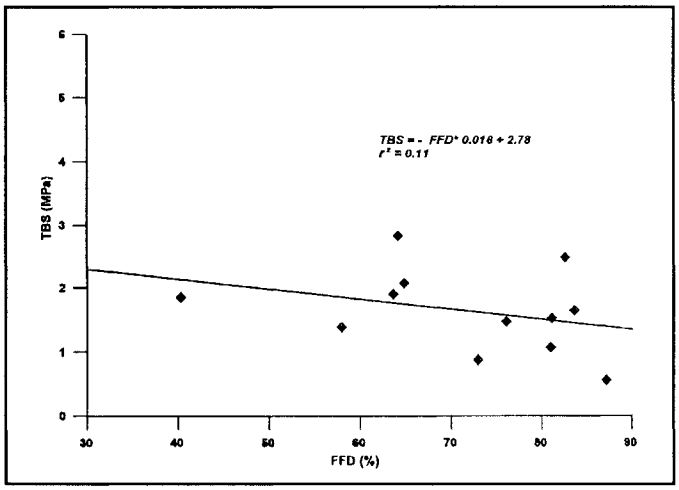

Figure 5. *Plot of final decrease of permeability (FFD) versus total bond strength (TNS) for DYR*

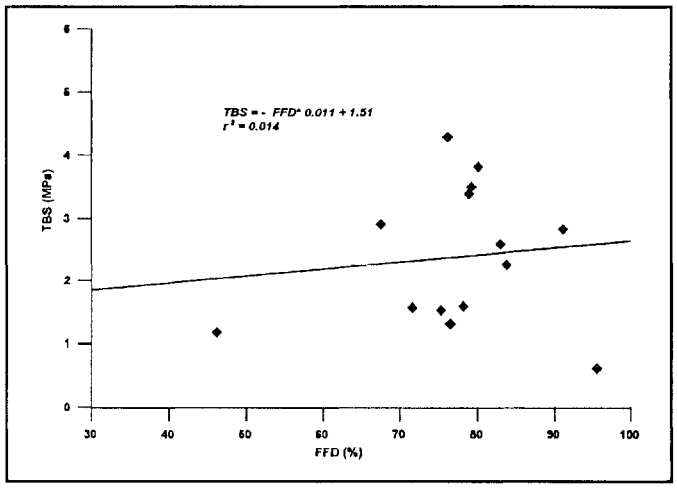

Figure 6. *Plot of final decrease of permeability (FFD) versus total bond strength (TBS) for COM*

does not mean, in our opinion, that there was fluid flow through the bonded interface.

Morphological studies have detected the existence of a gap between materials and dental tissues (Perdigao & others, 1996), but the absence of such a gap in the microscopic preparations does not guarantee either a perfect interphase, or that the materials are impermeable to fluids. Our methodology permits better discrimination and indicates that hermeticity does not exist. According to Prati, "There is invariably a gap between restoration and tooth . . . , allowing fluid flow" (Prati, 1994).

Water Sorption

A more likely explanation of the residual fluid flow resides in the chemical characteristics of the materials we used in this study. All of them are known to absorb water and this absorption can happen through the DBA layer, thus producing a false residual permeability. Yet such water absorption is an unappreciated phenomenon. Yap and Lee (1997) have measured the aqueous absorption of, among others, one of the composite resin materials we used in our study, Z100. They reported a water absorption, within 7 days, of 28.79 (SD = 1.165) µg of water/mm^3 of material, with an exposed area of 400.55 mm^2. Operating with their data, we can estimate that such material has an absorption of 7.1316E-6 µg of water/ mm^2 of exposed surface, per minute. Observations must be made about: (1) the rate of absorption not following a linear model because there must be a lag time before the material is saturated with water, and (2) when the absorption rate through the interface becomes equal to the evaporation rate through the exposed surfaces. When this equilibrium has been reached, the material will absorb water only to balance the evaporation rate. In our model, water absorption occurred through a surface covered with a DBA, a fact which will probably influence its rate.

Table 3. Total Volume of Water Absorptions of Materials after 25 Minutes

Material	µL H_2O/mm^2 of Exposed Surface
Spectrum	0.046
Prodigy	0.101
Z100	0.068
Dyract	0.091
Compoglass	0.065

Moreover, the cited work used overdried material, unlike ours, and submerged all surfaces of the samples in distilled water. In our model, water absorption could only occur through the DBA-dentin interface. It can be expected that, for the materials used in our study, the water absorption was probably higher than that reported by Yap and Lee (1997).

Our data (unpublished observations) showed that, in the first 25 minutes, some of the materials that we tested had extremely low equivalent water absorptions, as cited in Table 3.

Such values of water absorption do not seem to be responsible for the perfusion values that we recorded, as our measurements had a sensitivity of ±1 µL, and the system did not have enough sensitivity to perceive such small changes.

Tensile Bond Strength (TBS)

The values found for the resin bond strength were very low, which may well have been due to "the effect of the presence of defects and/or stress risers at the interface or in the substrate" (Sano & others, 1994). According to Griffith's theory (Griffith, 1920), it is more probable to find a defect that initiates the fracture in a larger area than in a smaller one. To support this idea, we have found cohesive fractures of dentin and restorative materials at very low apparent bond strengths (not included in the data), i e, < 5 MPa.

There was an enamel collar surrounding the dentin area, which contributed to the total bond strength. However, regardless of whether we used the total tooth surface or the dentin surface in the calculations, our values were very low.

Correlation of FFD/TBS

The correlation between reductions in fluid flow and bond strength were very poor for all the materials tested. We think this was due to the very low bond strength values that were found. According to Sano and others (1994) and Pashley (1997), if we use a material such as Clearfil Liner Bond II, the relation between TBS and the bonded surface (BS) should follow the formula $TBS = 58.8 - 27.9 \times \log_{10}(BS)$. For a bonded surface of 88.8 mm^2 (mean bonded surface area in our work), this equation would predict a TBS = 4.4 MPa. We think our results fit acceptably with such a prediction, taking into account the estimation error, the differences of materials, and the higher variability that occurs when the areas increase. In fact, our best-rated material (P&B) had a TBS of 3.96 MPa (Table 2). There was also almost a 40% decrease in the number of TBS samples (43) after the fluid flow tested 71 samples. The loss in specimens was due to the approximate loss of 75% of

the P&B specimens between these testing sequences. Specimens were discarded when any abnormality was detected at the moment the filtration device was assembled to the traction machine (almost exclusively "spontaneous" separation) or when, unintentionally, any of the parameters of the traction were not fulfilled properly (mainly crosshead speed).

Clinical Consequences

The clinical consequences of this work are that it may be impossible to create a hermetic seal in any restoration, at least with the materials tested. The fact that the clinical behavior of these materials is considered acceptable leads us to believe that a hermetic seal is neither necessary nor even possible. There will always be a passage of water, at least in an outward direction, that could be interpreted as an interchange of fluids towards and (probably) from the environment, through the restorative materials. It is the rate of such interchange that decreases but does not cease following restoration of cavities. Apparently this small fluid exchange is acceptable to the dentin-pulp complex. This may be a case where the sensitivity of a measuring device is so high that its detection is beyond clinical relevance (Pashley, 1997).

Nevertheless, the fact that there is a path for fluids through the interface means that restorative/adhesive materials are in a detrimental environment, although there would be no clinical evidence of such fluid flow. In this case, hydrolytic stability of materials becomes critical. The best interface (i e, maximum tightness) is achieved in the first stages of adhesion, and it can only become worse with time, especially in the oral environment.

Although we could not demonstrate the relationship between final decrease of fluid flow and TBS, it does not seem likely to us that higher TBSs would produce fluid flow cessation.

Unfortunately, it is impossible to select minimum bonding surfaces in a clinical situation, because they are determined by the type of cavity preparation, the skills of the operator, and the extent of the caries process. Recently, the bonding surface areas of different cavities were measured (de la Macorra & Gómez-Fernández, 1996). Class 1 cavities have a mean bonded surface area of 39.94 ± 7.54 mm^2, class 2 cavities 76.38 ± 24.61 mm^2, and class 5 erosions of 17.75 ± 5.10 mm^2 ($P < 0.05$). In such large areas, one can expect that TBS would be lower than those that are measured using smaller surfaces.

The mechanical stress on clinically bonded class 5 cavity surfaces is not perpendicular to all surfaces simultaneously, although the restored cervical erosions are closest to a perpendicular stress. The above cited formula (Sano & others, 1994) predicted a TBS of about 24 MPa for a bonded surface area of 17.7 mm^2.

CONCLUSIONS

None of the materials tested in this study produced complete cessation of fluid flow. The residual permeability that was found was interpreted as due to the passage of water vapor through the material and the adhesive.

Tensile bond strength values were very low, which was consistent with the predictions of low bond strengths in specimens with very large surface areas.

No correlation was found between tensile bond strength and the ability of any material to seal dentin.

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Effect of Bonded Amalgam Restorations on Microleakage

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Clinical Relevance
Microleakage was significantly reduced when Amalgambond Plus and All-Bond 2 were used as liners in comparison to either Copalite varnish or no liner under amalgam restorations.

SUMMARY

The purpose of this study was to evaluate quantitatively the effectiveness of adhesive dentin bonding systems in decreasing microleakage at the tooth-amalgam restoration interface. The results indicated that microleakage was significantly reduced when Amalgambond Plus or All-Bond 2 was used as liners in comparison to either Copalite varnish or no liner under amalgam restorations. No significant difference was found between the two dentin bonding systems at all time periods studied.

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INTRODUCTION

Silver amalgam has been used successfully, for over a century, as a restorative material. The popularity of this material is a result of its several distinct advantages such as relatively low cost, ease of manipulation and placement, good wear resistance, low technique sensitivity, acceptable life expectancy, and self-sealing ability (Leinfelder, 1993). However, its lack of adhesion to tooth structure, marginal leakage, susceptibility to tarnish and corrosion, and loss of marginal integrity have either restricted its use or limited its success (Reese & Valega, 1985).

Attempts have been made to prevent the microleakage associated with amalgam restorations by the use of cavity varnish, which minimizes initial microleakage until amalgam corrosion products can seal the marginal discrepancy (Andrews & Hembree, 1980). More recently, Zardiackas and Stoner (1983) introduced the concept of bonding amalgam restorations to tooth structure, and since then, the use of adhesive resin bonding materials, which are also very resistant to dissolution, has been advocated. Although the adhesive bonding systems presently available have greatly improved marginal sealing of

restorations, they are still not capable of completely eliminating microleakage (Chan & others, 1995; Inai & others, 1995).

The purpose of this study, therefore, was to evaluate quantitatively the effectiveness of adhesive dentin bonding systems in decreasing microleakage at the tooth-amalgam restoration interface.

METHODS AND MATERIALS

Tooth Selection and Preparation

A total of 24 extracted, unerupted, noncarious human third molars were used as the experimental teeth, within 1 month after extraction. The teeth were cleaned of hard and soft tissue accretions and stored at room temperature in a glass container in isotonic saline solution (pH 7.4) containing 0.2% sodium azide (Mallinkrodt Organic Reagent Inc, Paris, KY 40361) as an antimicrobial agent. All the teeth were sterilized in a steam autoclave (Amsco Eagle Services 200, American Sterilizer Co, Erie, PA 16514) at 122°C at 15 psi, for 30 minutes without the dry cycle, and stored in the same sterile glass container at room temperature as recommended by Pashley, Tao, and Pashley (1993). The specimens were then prepared in the manner described by Pashley and Depew (1986) (Figure 1).

Experimental Groups

This study was designed with four experimental groups. Six samples were randomly assigned to each group, according to the material placed as cavity liners to control microleakage around the amalgam restorations. Group 1: unlined Dispersalloy amalgam restorations (Caulk/Dentsply, Canada Ltd, Wood Bridge, Ontario, Canada, L4L 4A3; Lot No 940923) served as the control group; Group 2: Copalite varnish liner (Cooley and Cooley, Ltd, Houston, TX 77041, distributed by Denco, Toronto, Ontario, Canada, No 749,471) plus Dispersalloy amalgam restorations; Group 3: All-Bond 2 adhesive dentin bonding system (Bisco Inc, Itasca, IL 60143, Lot No 129033) plus Dispersalloy amalgam; Group 4: Amalgambond Plus adhesive dentin bonding system (Parkell, Farmingdale, NY 11735, made in Japan, Stock No S370) plus Dispersalloy amalgam.

Cavity Preparation, Lining, and Restoration

The crown segments were connected to a fluid under pressure using the apparatus described by Pashley and Depew (1986) and Derkson, Pashley, and Derkson (1986) (Figure 1). The pulp chambers and the tubes were both filled with isotonic saline solution at all times. Methylene blue dye was added to the fluid to assist in the visualization and photographic recording of the microleakage pattern. Cylindrical occlusal cavities were prepared in dentin using a #169 tapered carbide fissure bur followed by a #57 plain fissure bur at high speed with water coolant. A new bur was used for every six samples. The cavity dimensions were 3 mm in diameter and approximately 3.5 to 4 mm deep. Permeability of the dentin of each specimen was measured following cavity preparation.

Copalite treatment involved two applications of varnish to the cavity walls in a manner described by Ben-Amar, Cardash, and Liberman (1993). All-Bond 2 and Amalgambond Plus adhesive systems were applied according to the manufacturers' instructions. No Resinomer, liner F, or high-performance additive (HPA) powder was used. The specimens were restored with amalgam condensed in small increments. Prior to carving with a discoid-cleoid carver (4/5 HuFriedy Mfg Co, Chicago, IL 60618), the amalgam was burnished with a ball burnisher (BB D2 18 HuFriedy). All the teeth were kept for 30 minutes at room temperature after amalgam condensation, then returned to the saline solution storage medium at 37° C. All restorative procedures and specimen storage were at zero pulpal pressure while connected to the apparatus to ensure dentin hydration.

Cavity Permeability Measurements

As dentin permeability is directly related to the fluid flow rates across the dentin via the dentinal tubules, it was measured and quantified from the movement of the air bubble (mm/min) in the micropipette and expressed in (µl/min). The first permeability measurement was made with enamel intact prior to

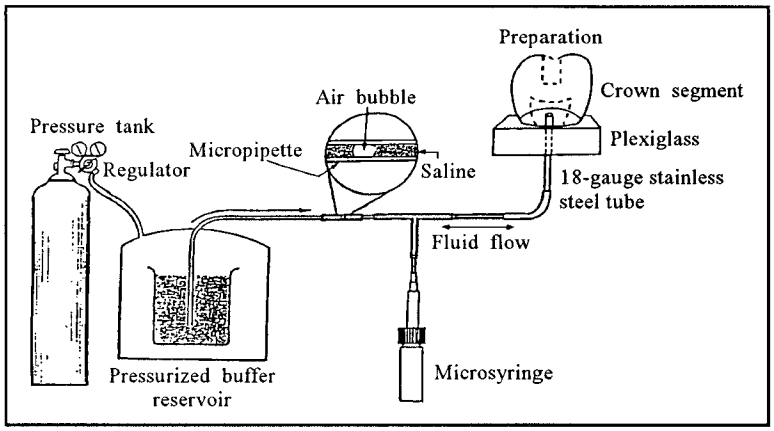

Figure 1. *Apparatus used to measure the dentin permeability and microleakage. The movement of the air bubble toward the chamber was used to determine the rate of fluid movement across the dentin to the cavosurface margin of the restoration.*

Table 1. Microleakage Values

Source	DF	Sum Squares	Mean Squares	*F*-Values	*P*-Values
Group	3	11.18860928	3.72953643	100.84	0.0001
Condition	5	8.02205525	1.60441105	43.38	0.0001
Grp*Cond	15	3.47854611	0.23190307	6.27	0.0001
Samples (Group)	18	6.56217213	0.36456512	9.86	0.0001

tooth preparation. This was done to check for abnormally high permeability in the tooth due to cracks or other defects, and also for leaks in the system. Defective teeth were discarded. The second permeability measurement was made after the cavity was prepared to check for any pulp exposure. Teeth that showed any pulp exposure or high dentin permeability were discarded. The third measurement was after acid etching the entire cavity with 37% phosphoric acid for 30 seconds to remove the smear layer created by cavity preparation, thereby maximizing dentin permeability (Pashley & others, 1993). This value was then assigned as the maximum dentin permeability (i e, 100%). Due to variations in dentin permeability between different teeth, any subsequent change in dentin permeability was then expressed as a percentage change from the maximum permeability of the etched specimen. Therefore, each tooth served as its own control. The fourth measurement was after the creation of a new standardized smear layer on the dentin surface using a #57 plain fissure bur at low speed for 1 minute but only removing minimal dentin. This measurement was then assigned as the minimum dentin permeability for each sample. Quadruplicate measurements of dentin permeability were taken for each treatment stage to assure the replicability and the accuracy of the readings. For each test condition the tooth was connected to the apparatus for 15 minutes, measurements were taken every 2 minutes, and only the last four consistent readings were used. For both Amalgambond Plus and All-Bond 2 groups, an additional measurement was taken after treating the dentin surface with an etchant supplied by the manufacturer. If this value was higher than the maximum value (i e, after acid etching with 37% phosphoric acid), it was then considered as the new maximum value for that specimen.

Microleakage Measurements

Microleakage was measured in (µl/min/cm H_2O) and expressed as an apparent reduction in the maximum dentin permeability of each specimen as a result of the treatment provided. Microleakage was measured after amalgam insertion at the following time intervals: 24 hours, 1 week, and at 1, 3, and 6 months. The applied pressure was 1124.912 cm of water.

Statistical Analysis

The microleakage values for each group of materials were compared longitudinally using a repeated-measures ANOVA (Table 1). Data were transferred into log percentages. Least square means contrasts were used for pair-wise comparisons with Bonferroni adjustment *P*-values ($P < 0.05$). A statistical package, SAS, was employed for this purpose (SAS Institute Inc, Cary, NC 27513).

RESULTS

Effect of Etching on Permeability

Table 2 represents the mean values of microleakage as a percentage of maximum together with the standard deviation (SD). The values for maximum

Table 2. Mean Values of Microleakage (µl/min/cm H_2O), ± SD

MATERIAL	PERMEABILITY		TIME AFTER INSERTION				
	Maximum	Minimum	24 Hours	1 Week	1 Month	3 Months	6 Months
Unlined	11.34 ± 3.06	2.78 ± 0.87	0.86 ± 0.22	0.77 ± 0.35	1.51 ± 0.17	2.91 ± 1.76	4.64 ± 4.47
Copalite	12.02 ± 2.62	2.49 ± 1.06	0.35 ± 0.14	0.62 ± 0.17	0.38 ± 0.07	0.66 ± 0.32	0.56 ± 0.16
Amalgambond Plus	25.41 ± 20.40	2.59 ± 2.38	0.35 ± 0.18	0.43 ± 0.26	0.54 ± 0.20	0.36 ± 0.18	0.37 ± 0.23
All-Bond 2	17.19 ± 13.40	2.60 ± 1.66	0.28 ± 0.06	0.31 ± 0.07	0.32 ± 0.11	0.21 ± 0.09	0.29 ± 0.15

Mean values (x 10^{-4}); N = 6.

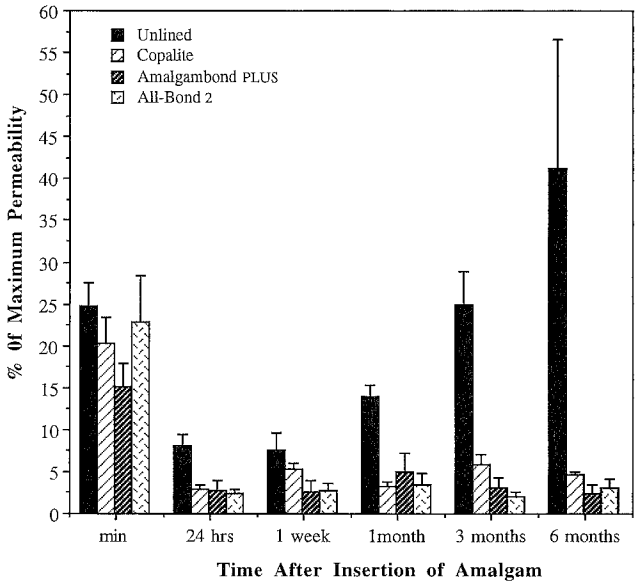

Figure 2. *The effect of different cavity liners on dentin permeability under different conditions and at different times (±SE)*

dentin permeability of the empty cavities were determined after removal of the smear layer with 37% phosphoric acid for both unlined and copalite restorations. However, a 10-3% citric acid-ferric chloride solution for Amalgambond Plus was used and 10% phosphoric acid was used for All-Bond 2 adhesive restorations. The Amalgambond Plus group showed the highest permeability (25.41 $x10^{-4}$ µl/min/cm H_2O), although this was not statistically significantly different from the other groups.

Effect of Smear Layer on Permeability

Creation of new smear layers reduced the permeability to values from 15.1% to 24.8% of the maximum permeability of those samples (Figure 2). This value was called "minimum permeability." All materials showed similar permeability reduction except the Amalgambond Plus group, which had lower permeability than the other tested groups but was not statistically significantly different. In general, microleakage in the unlined group tended to increase over observational time periods. On the other hand, microleakage of all the other groups remained around 3.5 % of their maximum values.

Effect of Time on Permeability of Restored Teeth (2-way ANOVA)

The apparent permeability of the restored cavities was significantly reduced 24 hours after insertion of the amalgam restorations compared to the unrestored cavities ($P < 0.05$). Microleakage was reduced to values between 8.1% and 2.5% for the unlined and the All-Bond 2 groups respectively. The unlined amalgam group showed statistically significant higher microleakage than the other groups ($P < 0.01$).

At 1 week, Amalgambond Plus and All-Bond 2 restorations had statistically significant lower microleakage than those obtained from the unlined amalgam ($P < 0.01$) and Copalite varnish restorations ($P < 0.05$).

At 1 month, most groups showed an increase in microleakage. Copalite, Amalgambond Plus, and All-Bond 2 all had statistically significant lower microleakage values than the unlined group ($P < 0.01$).

At 3 months, Amalgambond Plus and All-Bond 2 groups exhibited a statistically significant reduction in microleakage compared to both unlined ($P < 0.01$) and Copalite groups ($P < 0.05$). The unlined amalgam group had statistically significant higher microleakage than the Copalite group ($P < 0.01$).

At 6 months, Amalgambond Plus and All-Bond 2 had statistically significant lower microleakage than both the unlined ($P < 0.01$) and the Copalite groups ($P < 0.05$). The unlined group had a statistically significant increase in microleakage over that of the Copalite group; furthermore, it was significantly higher than unlined group results obtained at 24 hours, 1 week, and 1 month ($P < 0.01$).

DISCUSSION

The method used in this study provided a technique for quantitative assessment of microleakage between dentin cavity walls and the restorative materials in terms of dentin permeability. A major advantage was that the method did not require the destruction of the samples, thus making a longitudinal study feasible. Ideally, a restorative material should reduce the apparent permeability and, therefore, microleakage of the restoration to zero. This study demonstrated that removing the smear layers with a combination of citric acid and ferric chloride (10-3% solution) supplied with Amalgambond Plus or 10% phosphoric acid supplied with All-Bond 2 produced the highest dentin permeability (Table 2), which was above the 100% value. This may be partially explained by the fact that the dentin became thinner when further cavity preparation recreated the standard smear layer. This is in agreement with Fogel, Marshall, and Pashley (1988), who stated that as the remaining dentin decreases, its permeability increases.

Amalgambond Plus-treated samples exhibited slightly lower permeability (15.1%, which was not statistically significant at $P < 0.05$) than the other samples (Figure 2). This was due to the fact that Amalgambond Plus conditioners initially produced

the highest maximum permeability. The high variance of maximum permeability measurements for Amalgambond Plus as well as for All-Bond 2 may have been due to the effect of age and anatomical variability on the patency of the dentinal tubules in the third molar tooth samples. Pashley and others (1991) reported similar permeability, which was 23% of maximum. In that study they used a different etchant (0.5 M EDTA, pH 7.4) and measured dentin permeability by hydraulic conductance, i e, using a known surface area. Although it has been found that the smear layer decreases dentin permeability by blocking the dentinal tubules (Pashley & Depew, 1986), it also hinders sealing of amalgams (Jodaikin & Austin, 1981) and increases the microleakage around these restorations (Pashley & Depew, 1986). In contrast, acid etching dentin removes the smear layer and allows adhesive resins to bond to dentin structure. Thus, the amalgam, in conjunction with the cavity liner, can adapt better to cavity walls and reduce the interfacial space between the cavity walls and restorative materials through which fluid may flow (Pashley & Depew, 1986; Leelawat & others, 1992).

The apparent permeability or microleakage of all groups was greatly reduced 24 hours after insertion of amalgam restorations into the prepared cavities. This was an indication that the tested materials had sealed the dentin well and permitted little microleakage. It was expected that unlined amalgam restorations would show a slow decrease in permeability with time because of corrosion of the amalgam by the saline solution in which they were stored. Instead, there was a general increase in microleakage of unlined amalgams from 24 hours to 6 months (41% of the maximum) (Figure 2), a finding similar to that reported by Derkson and others (1986). This increase could have been caused by the slow dissolution of the smear layers resulting from fluid leakage (Pashley, 1990). Another possibility is the presence of bacteria, whose acidogenicity and metabolic activity could create a gap (1 to 2 μm) between the varnish and the original location of the smear layer (Pashley, 1990; Prati & others, 1994). This is unlikely in this study, as the teeth were stored in an isotonic saline solution containing the antiseptic, sodium azide; however, it is unknown whether the sodium azide solution had any effect on the solubility of corrosion products of the high-copper amalgam used in this study. For example, Fayyad and Ball (1984) showed that in vitro corrosive treatment improved the marginal seal of the low-copper amalgam, but had no effect on the marginal seal of high-copper amalgam. The high variance at 6 months for the unlined group was due to the fact that two samples out of the six tested exhibited high microleakage values (Table 2). These high values might have been due to the dissolution of the recreated smear layer by any residual microorganisms that survived (Meryon, Tobias & Jakeman, 1987; Meryon, 1988).

Generally, Copalite treatment in this study produced a highly statistically significant reduction in microleakage around the amalgam compared to unlined amalgams (4.63% of the maximum) (Figure 2). This was consistent with the findings of Pashley and Depew (1986) and Derkson and others (1986). However, the subsequent increased microleakage at 6 months suggested that two changes may be occurring simultaneously: dissolution of the underlying smear layer and dissolution of the Copalite varnish. Both changes may have increased the space between the cavity walls and amalgam restoration and hence increased microleakage. In contrast, there was no statistically significant difference between the resin groups at all time periods studied. In this in vitro study, bonded amalgam restorations sealed dentin effectively (microleakage values near zero) and controlled microleakage better than Copalite restorations for up to 6 months. Several microleakage studies reported the same findings when comparing Copalite to resin-lined amalgam restorations (Charlton & Moore, 1992; Charlton, Moore & Swartz, 1992). Saiku, St Germain, and Meiers (1993), in an in vitro study, showed that Amalgambond resin liner reduced microleakage significantly more than Copalite varnish or unlined amalgam restorations.

Nevertheless, the longevity of the marginal seal provided by resin liners remains an unanswered question. Furthermore, it is not known whether resin liners will remain more effective than Copalite over a long observational period. Moore, Johnson, and Kaplan (1995) found that there was no significant difference between the 4-META system and Copalite at 1 year. This was caused by an increase in average leakage of 4-META and decrease of average leakage in the Copalite group. However, it is not clear if this is the same with the Amalgambond Plus system, although they share the same adhesive monomer, i e, 4-META. Although bonded amalgam restorations in this study effectively reduced microleakage and showed a potential advantage over Copalite varnish, they did not completely eliminate microleakage. This small amount of microleakage might permit oral fluids, bacteria, or their products to irritate the pulp, causing postoperative pain or hypersensitivity, thereby allowing secondary caries to develop. Previous studies had identified this problem (Derkson & others, 1986; Saiku & others, 1993; Moore & others, 1995). However, the extent of microleakage that a human vital tooth can tolerate before jeopardizing pulpal health is unknown. In other words, the clinical significance of a 97% seal versus a 100% seal is not known. Since this study used higher pressure compared to the normal physiologic pulpal

pressure, and since less leakage occurs in vivo than in vitro (Barnes & others, 1993), the minute amount of microleakage detected in our study may actually not exist clinically.

The results of this in vitro study can be used to predict the clinical (in vivo) performance of the Amalgambond Plus and All-Bond 2 dentin adhesive systems; however, there are always other factors that may contribute and influence microleakage in vivo. Examples of such factors include pulpal pressure, thermal changes, masticatory forces, exposure to chemicals in oral environment, and type and duration of microleakage assessment. Future research should, therefore, be directed at evaluating the long-term efficacy of dentin bonding systems to reduce microleakage and dentin permeability under clinical conditions.

CONCLUSIONS

The results of this in vitro study indicated the following:

Microleakage was significantly reduced ($P < 0.05$) when Amalgambond Plus and All-Bond 2 were used as liners in comparison to either Copalite varnish or no liner under amalgam restorations.

No significant difference was found between the two dentin bonding systems at all time periods studied, i e, at 24 hours, 1 week, 1, 3, and 6 months.

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Retention and Shear Bond Strength of Two Post Systems

L W STOCKTON • P T WILLIAMS

Clinical Relevance
As a result of the high incidence of root fractures with each post system, especially the C posts, clinicians must evaluate each restorative situation and choose the system best suited for that circumstance.

SUMMARY

The purpose of this study was to compare the retention and shear strength of teeth restored with the Para Plus post (P) and the C post (C1 and C2) systems. Twenty-four P, C1, and C2 posts each were placed 7 mm into recently extracted and endodontically treated maxillary anterior roots and luted with Ketac-Cem and Bis-Core respectively. In addition, 13 samples of each post type had a Bis-Core composite core placed. The tensile retention strength of the post and the shear strength of the post and core restorations when the core was loaded buccolingually at 45° to the roots' long axis were determined at a strain rate of 1.3 mm/min. The C2 posts required significantly more tensile force ($P < 0.0001$) to remove them than the P or C1 posts. The shear strength of the post/core restorations was not significantly different ($P < 0.04$). The C1 restorations had 12 root fractures, the C2 restorations had 11 root fractures, and the P samples had six root fractures. It was concluded that the lack of stiffness of the C posts adversely affected the success of these restorations.

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INTRODUCTION

Endodontically treated teeth regularly receive posts and cores to provide predictable replacement of lost tooth structure and to facilitate crown support and retention.

Various types of posts and cores have been used, including individual cast posts and cores, and prefabricated posts with amalgam and/or resin composite cores. The major concerns that face the dentist include the long-term prognosis of the remaining root, the ability of the post to withstand stresses, the ease of placement, the compatibility of the post with other restorative materials, and the

ability to redo the restoration should it fail.

Many studies report that the failure rate of restorations with posts and cores is higher than that of restorations on vital teeth. Three surveys that looked at retainer and post crown failure (Roberts, 1970; Lewis & Smith, 1988; Turner, 1982) found that post crowns had the highest failure rate of major retainers, due in general to inadequate clinical and laboratory technique rather than to materials or to biological failure.

Failure can result from fracture or bending of posts, loss of retention, core fracture, or root fracture. Research into posts and cores continues in an effort to develop systems that are biocompatible, strong, retentive to dental cements, corrosion resistant, compatible with restorative materials, and that preserve root dentin and do not stress the root. The significantly higher survival rates of parallel-sided posts have led to a decline in the use of custom-cast posts and cores (Lewis & Smith, 1988; Torbjörner, Karlsson & Ödman, 1995; Sorensen & Martinoff, 1984a; Abou-Rass, 1996; Freedman, 1996). Despite the steady evolution of post and core materials and techniques, the failure of the post-retained crown is relatively common (Lewis & Smith, 1988; Torbjörner & others, 1995; Mentink & others, 1993; Sorensen & Martinoff, 1984b). The performance of build-up systems for endodontically treated teeth in these studies reported failure rates ranging from 1.6% to 4.6% per year. Loss of retention was the most frequently cited reason for failure, while root fracture was the most severe. The highest post-failure rate was found in maxillary anterior teeth. Sorensen and Martinoff (1984a) suggested that dentists should focus less on the factors that influence retention and concentrate more on factors that affect resistance to root fracture.

Several variables that can affect the results are involved when comparing the resistance to loading of different post systems. Variables include root morphology: the amount of remaining dentin (Guzy & Nicholls, 1979; Mattison, 1982; Tjan & Whang, 1995), post shape (Standlee, Caputo & Hanson, 1978), post diameter (Standlee & others, 1978; Stern & Hirschfeld, 1973, Johnson, Schwartz & Blackwell, 1976; Abou-Rass & others, 1982; Goodacre & Spolnik, 1995), and choice of luting agent (Standlee & others, 1978; Chapman, Worley & von Fraunhofer, 1985; Radke, Barkhordar & Podesta, 1988; Young, Shen & Maryniuk, 1985). We believe, as do others (Lambjerg-Hansen & Asmussen, 1997; Arvidson, Brunell & Soremark, 1982; Caputo & Standlee, 1987), that the success of these restorations is highly dependent on the stiffness and strength of the post.

Practitioners would welcome a reliable, easy-to-use post system that makes the placement and the success of a fixed restoration more predictable. The C post kit (Bisco Dental Products, Itasco, IL 60143), which has recently been introduced to the market, may be such a system. It consists of posts with three different diameters (#1, 2, and 3) and corresponding drills, one set of A and B Primers, and a bottle of Pre-Bond Resin.

The manufacturer (Bisco Dental Products advertisement, *Dentistry Today*, 1997) advertises the following advantages over competing products: The post cannot break down due to corrosion like some metal posts, they are radioparent (easily seen on radiographs), and they feature a strong tensile strength. They have almost the same modulus of elasticity as dentin, which means that when used with modern bonding materials, a monobloc post/core restoration is created to dissipate and absorb stress instead of transferring it to the vulnerable root structure. Currently, there has been only minimal investigation of these claims (Purton & Payne, 1996; Sidoli, King & Setchell, 1997; Isidor, Odman & Brondum, 1996). Purton and Payne (1996) found that under transverse loading, composite cores were retained more strongly to Para Posts (Whaledent International, New York, NY 10001) than to Composiposts (RTD, Meylan, France). Sidoli and others (1997) found that under a compressive load Composipost-restored teeth exhibited inferior strength properties in comparison to Para Post-restored teeth. Isidor and others (1996) concluded that the failure rate of Composipost-restored teeth under a shear load was significantly lower than that of Para Post and cast post systems evaluated in a previous study. It should be noted that in both of these studies the load was applied such that both a shear and compressive component was present. In both studies, failure would have been a shear failure.

The manufacturer makes claims that have been only minimally investigated and have not been substantiated. Therefore, the purpose of this study was to compare the in vitro retention and shear strength of the C post and the Para Plus post when placed in endodontically treated human teeth.

METHODS AND MATERIALS

Seventy-two extracted maxillary incisors and canines were selected for use based on dimensional requirements that ensured a minimum of 1.5 mm of dentin approximal to the post space at the coronal surface following post preparation. This was done to reduce the variation caused by different morphologies and remaining dentin. All samples were examined under X2 magnification to ensure a fracture-free root. The teeth were stored in tap water at 37 °C until required for experimentation.

The selected teeth were randomly assigned to six experimental groups. Groups 1, 2, and 3, which consisted of 11 teeth each, were used to evaluate the

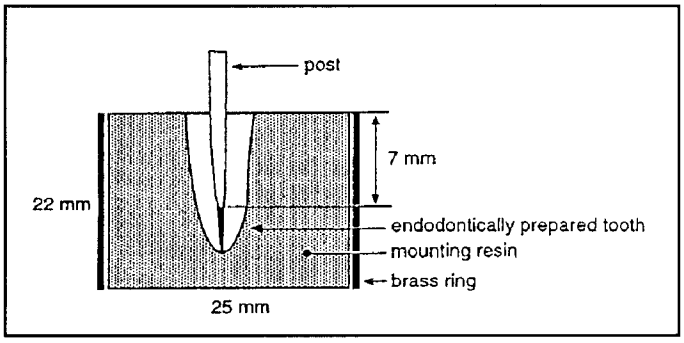

Figure 1. *Configuration of Groups 1, 2, and 3 samples mounted in resin in a brass ring*

post retention. Group 1 received a Para Plus post (Whaledent) and Groups 2 and 3 received a #1 and #2 C post (Bisco) respectively. Groups 4, 5, and 6, which consisted of 13 teeth each, were used to evaluate the shear strength of teeth that had been restored with a post and core. Group 4 received a Para Plus post and a Bis-Core (Bisco) composite core, and Groups 5 and 6 received a #1 and #2 C post respectively and a Bis-Core composite core.

The crowns of all 72 teeth were removed, using a carborundum disk, to a level 1 mm coronal to the CEJ. Endodontic treatment of all roots was performed, employing filing and shaping with hand instruments (Gates Glidden drills #2, #3, and #4; Moyco Technologies, York, PA 17402) to flare the coronal half of the canal space and vertical condensation of the gutta percha with Kerr's Pulp Canal Sealer (Kerr Mfg Co, Orange, CA 92867) placed on the apical 5 mm of the gutta percha point. The roots of Groups 1, 2, and 3 were mounted vertically in methylmethacrylate resin (Instant Tray Mix; Lang Dental Mfg Co, Inc, Wheeling, IL 60090) as shown in Figure 1.

The roots of three groups of 11 teeth (Groups 1, 2, and 3) were prepared, with the Whaledent Para Plus drills and the C post drills respectively, to a depth of 7 mm below the coronal surface of the root. The desired post, a #6 Para Plus post (1.5 mm in diameter), a #1 C post (1.4 mm in diameter), or a #2 C post (1.8 mm in diameter) was tried in the prepared canal to ensure a passive fit.

The post space was washed and dried with compressed air and paper points. For the #6 Para Plus post, Ketac-Cem (ESPE, Norristown, PA 19404) was mixed according to the manufacturer's instructions and placed in the post space with a hand-held lentulospiral and onto the post. For the #1 and #2 C posts, the posts were microetched (Danville Engineering, San Ramon, CA 94583) and painted with two coats of Primer B. The post space was etched for 15 seconds with 32% phosphoric acid (Uni-etch; Bisco), then washed and dried for 3 seconds with compressed air. Any excess moisture was removed with paper points. Two coats of a mixture of Primers A and B were placed onto the dentinal walls with a microbrush and thoroughly air dried for 5 seconds. A paper point was used to remove any excess primer from the canal floor. Using a paper point, a coat of Pre-Bond Resin was applied to the already primed canal and air thinned with an air syringe. Bis-Core paste was mixed according to the manufacturer's instructions and placed evenly onto the posts. The posts were seated and held in place until the initial set had occurred. All prepared samples were left standing for an additional time (10 minutes for the Para Plus posts and 5 minutes for the C posts) to achieve complete setting of the luting agent.

After 48 hours of storage in 37 °C water, the mounted specimens were loaded in tension (Rheile FS-5 Screw Power Testing Machine; American Machine and Metals, East Moline, IL) at a strain rate of 1.3 mm/min until failure occurred. The load at failure was recorded and the data analyzed using Student's *t*-test.

The roots of three groups of 13 teeth were prepared using the same technique as for Groups 1, 2, and 3. The 39 samples were mounted in methylmethacrylate with the methylmethacrylate 3 mm apical to the coronal surface of the root (Figure 2). Number 6 Para Plus posts, #1 C posts, and #2 C posts were luted to place. The coronal portion of the root surface of the Para Plus samples was etched for 30 seconds with 32% phosphoric acid (Uni-etch), washed thoroughly, lightly dried, and painted with seven coats of a mixture of Primers A and B. The coated surface was thoroughly air dried for 5 seconds. A coat of Pre-Bond Resin was placed on the coronal root surface and air thinned. An IB-Swiss (IB Williams AG, Mauren, Switzerland) crown form was filled with the composite core material

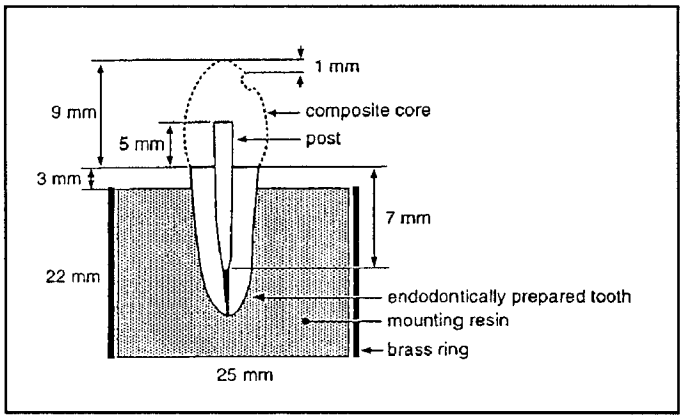

Figure 2. *Configurations of Groups 4, 5, and 6 samples mounted in resin in a brass ring*

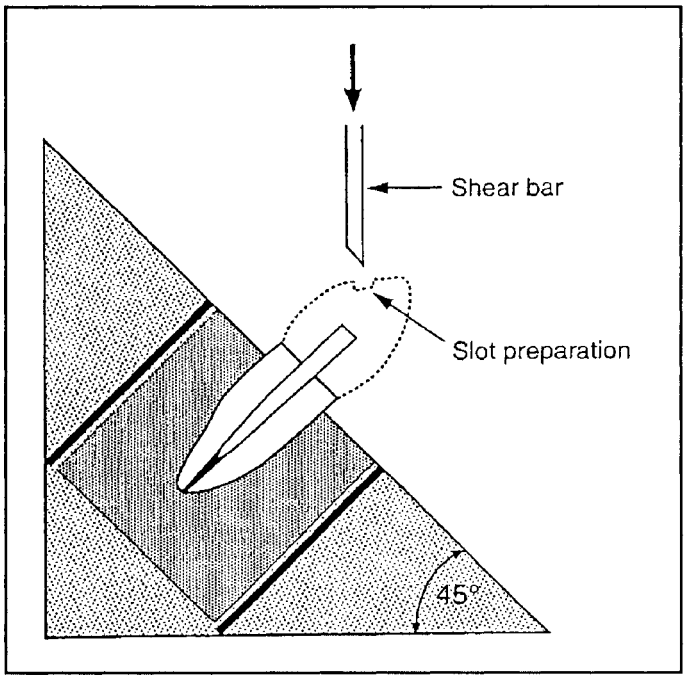

Figure 3. *Sample holder with mounted sample showing slot preparation. Note that the base of the slot is 1 mm from the incisal edge and is perpendicular to the direction of the load application. The arrows show the direction of the load application.*

(Bis-Core), which had been mixed according to the manufacturer's instructions. The filled crown was seated and held in place until the set had occurred.

The Group 5 and 6 samples had the coronal portion of the root surface and the C post microetched (Danville Engineering). The coronal surface was washed and dried, then etched for 30 seconds with 32% phosphoric acid, washed thoroughly, and lightly dried. The C post was thoroughly dried and painted with two coats of Primer B; the coronal surface of the root received seven coats of a mixture of Primers A and B and a coat of Pre-Bond Resin, which was air thinned. An IB-Swiss crown form was filled with the composite core material (Bis-Core), which had been mixed according to the manufacturer's instructions.

The filled crown form was seated and held in place until the set had occurred. All samples were set aside for an additional 10 minutes to ensure complete set of the composite material. Subsequently, the IB-Swiss crown form was peeled off all samples. The cores were reduced until they conformed to an overall length of 9 mm from the coronal surface of the root to the incisal edge of the core. Excess composite material on the approximal surfaces was removed using a high-speed diamond (Brasseler #863EF; Brasseler USA, Savannah, GA 31419) and water spray, coarse Pop-On disks (3M Dental Products, St Paul, MN 55144), and finally, composite knives (American Dental Mfg Co, Chicago, IL 60618) to ensure a butt-joint at the root/composite interface (Figure 2).

After 48 hours of storage in 37 °C water, all samples were mounted into a custom-made mounting block, which aligned the samples at 45° to the vertical. A slot whose bottom surface was perpendicular to the applied load and 45° to the long axis of the post was prepared on the lingual surface of the core 1 mm from the incisal edge. An increasing load at a strain rate of 1.3 mm/min was applied to the base of the slot (Figure 3) until failure occurred (Rheile FS-5 Screw Power Testing Machine). The load at failure as well as the site of failure was recorded and the data analyzed using Student's *t*-test.

RESULTS

The strengths of the luted P and C posts are shown in Table 1.

The load to dislodge the P posts ranged from a low of 6.12 kg to a high of 14.06 kg; whereas for the #1 C posts, the range was from 5 kg to 19.8 kg and from 16.78 kg to 44.9 kg for the #2 C posts. There was no statistical difference between the P posts and the #1 C posts ($P < 0.05$); however, the #2 C post was significantly different from the other two ($P < 0.0001$).

Table 1. Mean Load Required to Debond the P and C Posts from the Endodontically Prepared Teeth

Post Type	Mean Load	SD
P Post	9.1 kg	2.4
#1 C Post	10.6 kg	5.0
#2 C Post	31.3 kg	9.4

Vertical line joins values that are not statistically different (Student's *t*-test $P < 0.0001$).

Table 2. Mean Shear Failure Loads for the Post and Core Restored Teeth

Post Type	Mean Load	SD
P Post/Core	23.7 kg	6.90
#1 C Post/Core	21.3 kg	7.39
#2 C Post/Core	25.8 kg	6.35

Vertical line joins values that are not statistically different (Student's *t*-test $P < 0.04$)

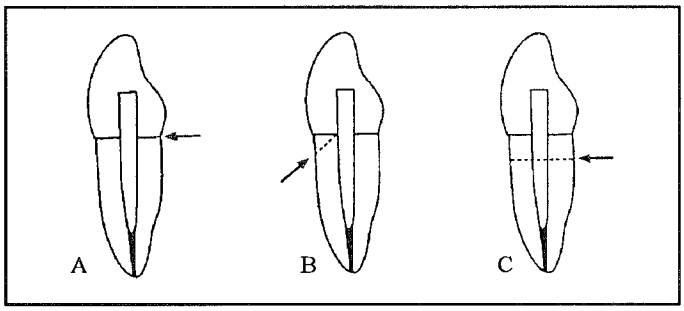

Figure 4. *(A) Adhesive failure at the core/root interface (B) Diagonal fracture of the labial portion of the root (C) Horizontal fracture through the root*

The site of failure for all the P posts was between the cement and the post, and the site of failure for all the C posts was between the luting agent and the tooth.

The shear load at failure of the post and cores is shown in Table 2.

All samples experienced a peak load and then, for most, the load would fall gradually and spasmodically until catastrophic failure occurred. The load recorded was the peak load.

The load required to cause failure of the P post and core ranged from a low of 13.6 kg to a high of 36.2 kg; whereas the range for the #1 C post and core was 10.23 kg to 35.23 kg and the #2 C post and core was 15.42 kg to 35.38 kg. The analysis of variance revealed no statistically significant difference between the three systems ($P < 0.04$).

Seven of the P post/core samples, one of the #1 C post/core samples, and two of the #2 C post/core samples, failed at the core/root interface (Figure 4A). Six of the P post/core samples, 12 of the #1 C post/core samples, and 10 of the #2 C post/core samples failed as a result of a diagonal fracture of the root (Figure 4B). One #2 C post/core sample experienced a horizontal root fracture (Figure 4C). There was no post fracture in either the P post/core or the #2 C post/core samples. Four #1 C post/core samples experienced post fractures. All the fractures occurred 4 mm from the post apex, which coincided with the small end of the taper joining the large and small parts of the post (Figure 5).

DISCUSSION

The results of this study indicated that the application of a shear load was not encouraging for the C post. Whereas the load to cause failure was not significantly different for the three systems, the site of the failures for the C post gives cause for concern. Twelve of 13 #1 C post and 11 of 13 #2 C post samples failed as a result of root fracture compared with six P post samples. The reason for the large number of root fractures with the C post, we hypothesize, may be as the result of increased flexing of the coronal portion of the post that is not surrounded by dentin. This is supported by the respective moduli of elasticity for each post. The P post is made of stainless steel, which has a modulus of 160-180 GPa (O'Brien, 1997). At an applied load of 45° the C post material, because of its anisotropic properties, has a modulus of elasticity of 21 GPa as stated by the manufacturer, which makes it 1/8 as stiff as stainless steel. The slightly larger (20%) diameter of the C post increases its stiffness by about 100% (Popov, 1952). Even with this increase, the stiffness of the C post is only 1/4 that of the P post. The greater flexure of the C post under function may have created increased stresses in the surrounding composite core and the bonded and luted interfaces, resulting in an increased chance of subsequent root fracture.

The clinical implications of this flexure could be microleakage at the root/core interface, secondary caries, and the potentiality for root fracture, especially in maxillary anterior teeth with heavy occlusal function, and small fixed partial denture (FPD) abutments.

The decision was subsequently made to include the #1 C post in our study to more thoroughly evaluate the C post in comparison to the P post. Since the #1 C post did not have values significantly different from the P post, the high retention values of the #2 C post are likely a reflection of the surface area available and not the ability of the post and the luting agent to create a "monobloc" restoration as claimed by the manufacturer.

The location of the fracture of the four #1 C posts (Figure 5) gives cause to question the design of this post. King and Setchell (1990) described the failure of a carbon fiber-reinforced carbon (CFRC) post resulting from the progressive failure of individual

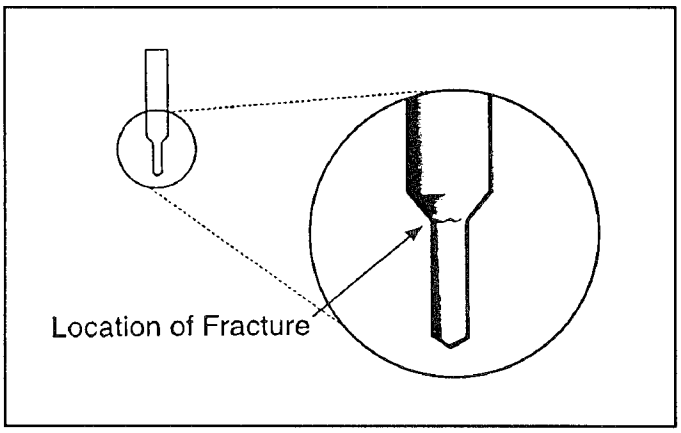

Figure 5. *Location of the fracture*

fibers. The location of the four failures in this study was at the point of the fewest individual fibers. The results further indicated that the #1 C post offered no valid reason to be considered over the P post. The #1 C post/core had the lowest failure load of the three systems at 10.23 kg; it also had the greatest number of root fractures and was the only system to experience post fractures. The #2 C post demonstrated very high retention values, and therefore could be considered in those cases where increased retention was required. However, this post requires a post hole diameter of 1.9 mm, and if the clinician wishes to retain a minimum of 1.5 mm (Mattison, 1982) of approximal dentin at the coronal surface of the root and no less than 1 mm at any point along the length of the post (Abou-Rass & others, 1982), then case selection for this post will be limited.

Although the use of extracted teeth may be questioned by some, their use is considered acceptable by most researchers for this type of study (Standlee & others, 1978; Lovdahl & Nicholls, 1977).

Practitioners must maximize resistance to root fracture. The amount of remaining tooth structure is critical.

Sorensen and Engleman (1990) found that a minimum of 1 mm of tooth structure coronal to the gingival margin of the crown improved resistance to fracture. Others (Eissman & Radke, 1987; Barkhordar, Radke & Abbasi, 1989; Hemmings, King & Setchell, 1991) have advocated preparing the tooth with a ferrule preparation to receive a cast restoration that extended 2 mm apical to the junction of the core and the remaining tooth structure to enhance fracture resistance of the tooth.

CONCLUSIONS

The results of this study indicated that there are no advantages to be gained by using the C post system over the P post system. Rather, since the retention strength of similar-sized posts are not different, and since the incidence of root fracture is greater when using C posts, the use of C posts may be undesirable for most cases.

Because shear load is impossible to simulate in vitro, the conclusions drawn from such studies should be interpreted with care. Clinical trials may be necessary to confirm the early findings for the carbon fiber post.

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Quantitative Microleakage Evaluation around Amalgam Restorations with Different Treatments on Cavity Walls

P M R DE MORAIS • A L RODRIGUES, Jr
L A F PIMENTA

Clinical Relevance
The use of hydrophilic adhesive systems or glass ionomer/composite resin hybrid materials on cavity walls before the restoration may help to reduce microleakage around freshly packed amalgam restorations.

SUMMARY

The purpose of this in vitro study was to evaluate the dye penetration around amalgam restorations in dentin cavities by a quantitative test. Standardized circular cavities were prepared on the facial surface of 75 extracted human single-rooted teeth, and restored with dental amalgam. Different bonding/sealing treatments were used on the cavity walls before the restorations were placed. The specimens were thermocycled between 5±2 °C and 55±2 °C for 500 cycles with 1-minute dwell times, followed by immersion in a 2% methylene blue solution for 12 hours at 37 °C. The quantitative microleakage was evaluated by spectrophotometry and was expressed by µg dye per tooth structure. The results showed that the use of bonded amalgam restorations was more effective in reducing microleakage.

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INTRODUCTION

Amalgam restorations have been used effectively for more than 150 years (Peyton & Craig, 1971). In spite of its physical properties, dental amalgam does not bond to tooth structure, and the interfacial space allows initial leakage around these restorations (Ben-Amar, Cardash & Judes, 1995; Moore, Johnson & Kaplan, 1995). However, this phenomenon decreases with time, which might be due to the deposition of corrosion products (Ben-Amar & others, 1995; Going, 1972; Jodaikin, 1981). Liners have been used to minimize marginal leakage around freshly packed amalgam restorations (Berry & Tjan, 1994; Saiku, St Germain & Meiers, 1993).

Cavity varnish has long been used to control initial microleakage (Andrews & Hembree, 1975; Ben-Amar & others, 1995; Silva & others, 1985), but, recently, there has been concern about the effectiveness of using this method to seal amalgam restoration

margins, especially when high-copper amalgam is used (Ben-Amar & others, 1995; Pimenta, Fontana & Cury, 1996; Powell & Daines, 1987; Turner, St Germain & Meiers, 1995).

Dentin bonding agents have been used as cavity liners for amalgam restorations. In in vitro studies, they have shown a significant decrease in microleakage (Ben-Amar & others, 1987; Saiku & others, 1993; Staninec & Holt, 1988; Yu, Wei & Xu, 1987) and inhibition of the progress of recurrent artificial caries (Pimenta & others, 1996; Torii & others, 1989). Clinical studies have also reported satisfactory behavior of the bonded amalgam restorations (Lacy & Staninec, 1989; Trushkowsky, 1991) over a 2-year evaluation period (Belcher & Stewart, 1997). Nevertheless, these authors concluded that 2 years is not sufficiently long enough to guarantee a proper evaluation of the clinical performance of bonded amalgam restorations.

The glass-ionomer cement and glass ionomer/composite resin hybrid materials have been used under amalgam restorations to reduce microleakage due to their adhesive properties (Arcoria & others, 1990; Shimizu, Ui & Kawakami, 1987; Youngson, Grey & Glyn Jones, 1990). The fluoride release from these materials and the inhibition of the development of secondary caries have led some investigators to recommend them as bases under amalgam restorations (Dionysopoulos, Kotsanos & Papadogianis, 1996; Rabchinsky & Donly, 1993; Pimenta & others, 1996).

In spite of the improvement in microleakage reduction with application of dentin adhesives and glass-ionomer cement or hybrid materials, the greater degree of marginal leakage occurs on the gingival margins (Ben-Amar, Cardash & Liberman, 1993; Moore & others, 1995; Saiku & others, 1993).

Most microleakage studies use dye penetration and qualitative analysis. These methods showed leakage that is probably incomplete, because the assessment of a section is a two-dimensional observation, but microleakage is a three-dimensional phenomenon (Rigsby & others, 1990; Taylor & Lunch, 1992; Youngson, Grey & Jones, 1990). Volumetric leakage may be obtained by quantitative tests that have been recommended (Silva & others, 1985).

The purpose of this in vitro study was to evaluate the effectiveness of different treatments on dentin cavity walls in reducing microleakage around freshly packed amalgam restorations using a quantitative test.

METHODS AND MATERIALS

Seventy-five extracted human single-rooted teeth, free of caries, were used. After extraction, the teeth were kept in 2% formaldehyde (pH 7.0). The selected teeth were washed and cleaned with pumice and water by means of rubber cups at low speed, and stored in distilled water for 24 hours. Standardized circular cavities 2.0 mm in diameter and 1.5 mm in depth were prepared on the facial surface of each tooth and finished using the same special bur (KG Sorensen Ind & Com Ltd Al Amazonas, 560 Alphaville São Paulo, SP, 06454920 Brazil) at slow speed. The cavity preparations were made on the roots, approximately 3 mm below the cementoenamel junction.

The teeth were randomly assigned into five groups. The groups were separated according to the treatment on cavity walls before restoration with an admixed alloy (Permite C; Southern Dental Industries Ltd, Bayswater, Victoria 3153 Australia). The treatment of each group was as follows: Group 1—control (no lining agent); Group 2—cavity varnish (Copalite; Cooley & Cooley Ltd, Houston, TX 77041); Group 3—adhesive resin cement (Panavia Ex; Kuraray Co Ltd, Osaka 530, Japan); Group 4—hydrophilic adhesive system (Scotchbond Multi-Purpose Plus; 3M Dental Products, St Paul, MN 55144; Group 5—composite resin-modified glass ionomer (Photac-Bond; ESPE, Seefeld/Oberbay, Germany), placed only on the axial wall.

The materials were mixed and applied according to the manufacturers' instructions.

All restored teeth were stored at 37 °C in 100% relative humidity for 24 hours before finishing and polishing. The teeth were thermocycled 500 times between 5 °C and 55 °C (±2 °C) alternately with a dwell time of 1 minute at each temperature, 12 hours after finishing. The root apices were sectioned with a double-faced diamond disk (KG Sorensen) and sealed with epoxy glue (Araldite; Brascola Ltda R Brascola,

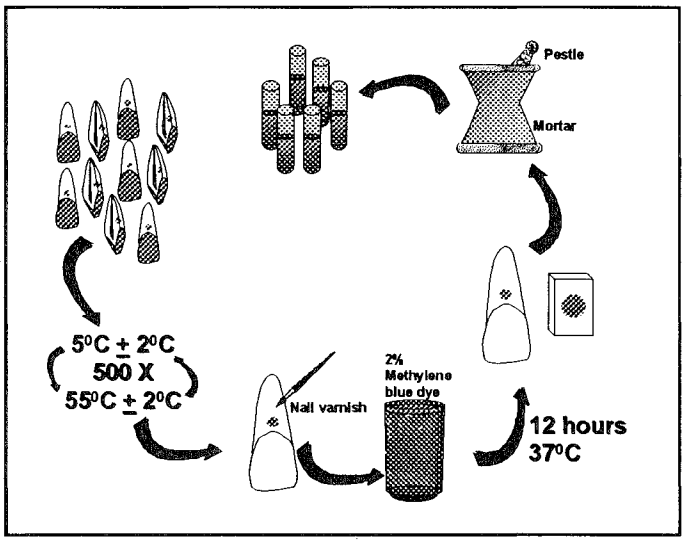

Figure 1. *Diagrammatic representation of the preparation of experimental units for spectrophotometric analysis*

Statistical Results Obtained by Kruskal-Wallis and Multiple Comparison Tests from Experimental Treatments of Cavity Walls for Dye Penetration Values

Experimental Treatments	Sample Size	Sum of Ranks**	Median Estimate	Group*
Control	15	998	10.610	a
Copalite	15	786	7.422	b
Panavia Ex	15	521	3.066	c
Photac Bond	15	365	1.941	d
SBMP+	14	105	0.234	e

*Different letters = significant difference at 5% probability level.
**Least significant difference for comparisons of sums of ranks was 37.6.

São Paulo, 09892110 Brazil). The whole tooth surface, except the restoration and 1 mm of tooth from its margins, were coated with two layers of fingernail varnish. Then each tooth was immersed in 2% methylene blue aqueous solution for 12 hours at 37 °C. The teeth were washed and the nail varnish removed from the tooth surface by scraping it off using a surgical blade.

The teeth were sectioned into dental blocks (6 mm high x 5 mm wide x 3 mm thick) including the restoration in the center, using a double-faced diamond disk. This procedure was performed to standardize the volume of the tooth used in the spectrophotometric analysis. Each dental block was individually ground with a metallic mortar and pestle, and then immersed into 5 mL ethyl alcohol for 24 hours (Figure 1).

Spectrophotometric Analysis of Samples

Before reading the sample in the spectrophotometer (Beckman DU-65; Beckman Instruments, Inc, Fullerton, CA 92634-3100), standard solutions of methylene blue dye (0,2,4,6,8,10 μg/mL) were prepared. Thirty more root sections, treated in an identical manner as the teeth tested but not exposed to methylene blue dye nor thermocycled, were utilized in the standard solutions. These solutions were centrifuged and read in the spectrophotometer to determine the maximum absorbence, which was 650 nm in this study, and to establish a standard calibration curve for each treatment.

After the calibration of the spectrophotometer with the blank solutions, the samples were centrifuged and the readings performed. The dye concentration was determined by standard calibration curves.

The quantitative microleakage was calculated as μg dye per tooth structure and the data analyzed by Kruskal-Wallis test and Multiple Comparisons test.

RESULTS

Statistical analysis by Kruskal-Wallis test ($\alpha = 0.005$) of microleakage data showed significant differences among all experimental treatments, and the Multiple Comparisons test (lsd = 37.60) identified these differences (table). The box-plot diagram illustrates the nonparametric values obtained in this test (Figure 2).

Comparing the sum of ranks among the treatments of the cavity walls before the amalgam restorations (table and Figure 2), significantly less dye penetration per tooth was showed by the hydrophilic adhesive system (Scotchbond Multi-Purpose Plus), followed by the glass-ionomer/composite hybrid material (Photac-Bond), adhesive resin cement (Panavia EX), cavity varnish (Copalite), and the control group, which exhibited the highest values of microleakage.

DISCUSSION

Many methods have been devised to test cavity-sealing properties in in vitro studies (Alani & Toh, 1997). Volumetric leakage studies have been recommended to measure the real leakage that occurred around restorations (Risgby & others, 1990; Youngson & others, 1990; Silva & others, 1985). Most microleakage studies use dye penetration and qualitative analysis, which is an incomplete assessment, because the analyzed section is a two-dimensional measurement, while the leakage is a

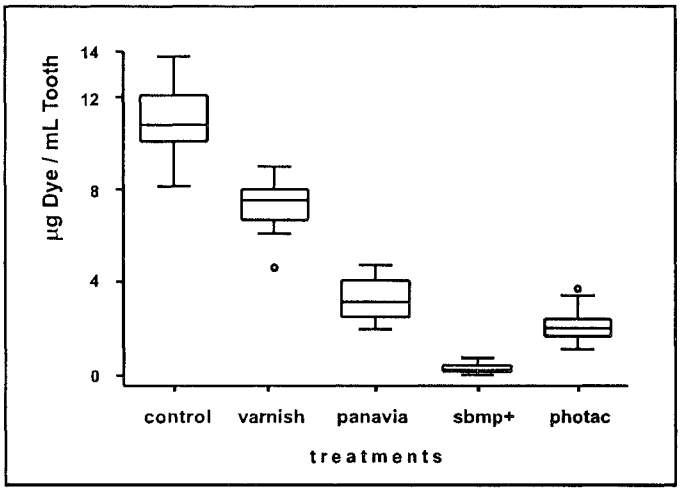

Figure 2. *Dye penetration in amalgam restorations by experimental treatment of cavity walls*

three-dimensional phenomenon (Youngson & others, 1990; Taylor & Lunch, 1992). Qualitative methods have the advantage of showing the pattern of dye penetration, and they could indicate if the dye leakage was at the restoration/linear interface and/or liner/tooth interface (Alani & Toh, 1997; Kidd, 1976; Youngson & others, 1990). Although the spectrophotometric analysis for microleakage gives the totality of the leakage around the restorations, it cannot show the pattern and extent of dye penetration. This limitation occurs because the dye presented in the specimens has to be dissolved before the reading in the spectrophotometer (Risgby & others, 1990; Silva & others, 1985). Both methods have been presented measuring system limitations. In order to get complete results these could be associated or another method should be developed.

According to the results of the present study, the use of the copal varnish as treatment on the cavity walls before the placement of the amalgam restoration showed a superior effect when it was compared to the control group, although its effectiveness in reducing the marginal leakage showed a lower effect than other tested treatments (table and Figure 2). The lack of adhesion to the dental structure and its high solubility may explain such behavior (Andrews & Hembree, 1975; Ben-Amar & others, 1990; Powell & Daines, 1987). Fitchie and others (1990) concluded that the space left after the dissolution of the varnish was too large to be self-sealed by the high-copper amalgam alloys. The manufacturer's instructions to use two layers of cavity varnish will lead to an increase in the thickness of this liner, which, in turn, may contribute to the formation of a greater space after its dissolution. According to Ben-Amar and others (1990) and Turner and others (1995), the dissolution may occur during the procedures of thermocycling, used in the studies of microleakage.

Reports on the reduction of leakage around amalgam restorations with the use of adhesive systems (Ben-Amar & others, 1990; Saiku & others, 1993; Staninec & Holt, 1988; Yu & others, 1987) do agree with the findings of the present study, in which lower values of the dye penetration were observed when Scotchbond Multi-Purpose Plus (SBMP+) was used as a liner (table and Figure 2). Despite this effectiveness, some investigators still question the duration of the adhesive capacity of these systems and consequently, the maintenance of low values of microleakage (Ben-Amar & others, 1995; Pashley, 1990; Varga, Matsumura & Masuhara, 1986). The resin cement Panavia Ex was not able to reduce the microleakage in the same way as the hydrophilic adhesive system (SBMP+). Though it has been shown to be superior to the control group and to the cavity varnish, it is inferior to the composite-resin-modified glass ionomer (Photac-Bond) (table and Figure 2). Although several studies demonstrated the effectiveness of using Panavia Ex in reducing leakage around amalgam restorations with enamel margins (Pimenta & others, 1996; Torii & others, 1989; Varga & others, 1986), Charlton, Moore, and Swartz (1992) did not observe any significant reduction of the microleakage around dentin margins of amalgam restorations lined with Panavia Ex, but an increased retention of the restorations was described. On the other hand, Turner and others (1995) reported good reduction in marginal leakage when a combination Panavia Ex/dentin bond system was used as treatment on cavity walls prior to the placement of amalgam restorations. This improvement may be caused by dentin acid etching and the use of a dentin adhesive. Nevertheless, the manufacturer only recommends acid etching the enamel margins before applying Panavia Ex on the cavity walls.

The use of the composite-resin-modified glass ionomer (Photac-Bond) as a base was more effective in reducing microleakage around amalgam restorations than the control group, the cavity varnish, and the resin cement (Panavia Ex). Nevertheless, it was not better than the adhesive system (SBMP+). This satisfactory performance in the use of glass-ionomer cement and the glass ionomer/composite resin hybrid materials has also been demonstrated in other studies (Arcoria & others, 1990; Dionysopoulos & others, 1996; Shimizu & others, 1987; Youngson & others, 1990).

According to Pashley (1990), the most important clinical sequelae of microleakage is secondary caries, which leads to the failure and later replacement of restorations (Dionysopoulos & others, 1996; Rabchinshy & Donly, 1993). The inhibition effect on the development of the experimental cavity wall lesions around glass-ionomer-lined amalgam restorations may be due to fluoride presence on the tooth/restoration interface (Dionysopoulos & others, 1996). The cariostatic potential of the glass-ionomer materials must be considered (Serra & others, 1996), especially in clinical situations, where not only the reduction of the marginal leakage is desired, but also, and particularly, avoiding the development of secondary carious lesions.

According to the results obtained and discussed in the present study, the use of dentin hydrophilic adhesive or glass ionomer/composite resin hybrid material under amalgam restorations suggested a satisfactory clinical performance, though the evaluation of the oral health conditions of the patient remains the most important factor for the successful behavior of any restorative procedure (Özer & Thylstrup, 1995). The effective control of individual caries activity may be explained by how many amalgam restorations without any bonding agent or liner have clinical success.

CONCLUSIONS

According to the conditions and results of this in vitro study, the following conclusions can be drawn:

1. The use of treatments on dentin cavity walls is important in reducing microleakage around freshly packed amalgam restorations;
2. The hydrophilic adhesive system was the most effective;
3. The glass ionomer/composite hybrid material exhibited a significant decrease in microleakage; and
4. The cavity varnish was the least efficient; however, it was significantly better than the control group.

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Bond Strength of Composite to Dentin Treated by Air Abrasion

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B OBSTER • R HICKEL

Clinical Relevance
Air abrasion is an effective method of dentin surface conditioning prior to adhesive bonding and is able to produce bond strength values comparable to acid etching.

SUMMARY

This study compared the bond strength of composite to dentin produced by an air-abrasive dentin pretreatment and acid etch only. Two hundred sixty extracted human molars were randomly divided into 13 groups (n = 20). An occlusal dentin surface with a defined smear layer was exposed. Dentin was conditioned either with 37% H_3PO_4 for 20 seconds, or an air-abrasion unit (KCP 1000, ADT) was used with 120 and 160 psi pressure and two different particle sizes, 50 and 27 µm. A combination of both treatments beginning with air abrasion was tested as well as dentin specimens without pretreatment. The dentin adhesive Syntac Single-Component was applied under dry and moist conditions. Composite cylinders with a bond diameter of 2.5 mm were bonded in two increments to the teeth. Specimens were stored for 24 hours at 37 °C in distilled water and then thermocycled for 1000 cycles (5/55°C). Shear bond strength was tested using a Universal Testing Machine at 0.5 mm/min crosshead speed. Means and standard deviations in MPa were calculated. Analysis of variance and Bonferroni pairwise comparison tests were performed.

Lowest bond strengths were obtained in specimens without conditioning the dentin. Air-abraded specimens showed a significantly higher bond strength than the before-mentioned groups. The comparison for acid-etched groups and air-abraded specimens revealed higher values for the abraded groups. Air abrasion with 160 psi pressure produced a significantly higher bond

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strength than 120 psi. There was no significant difference between the 27 and 50 μm particles. Air abrasion in combination with a self-priming bonding agent produced bond strength on dentin at least comparable to conditioning with 37% H_3PO_4.

INTRODUCTION

Modern esthetic dentistry is based in large part on adhesive bonding of composite resins and all-ceramic restorations to human dentin and enamel. Composite restorations can be inserted directly into the tooth or indirectly as an inlay or onlay. Ceramic inlays, onlays, veneers, and crowns are indirect restorations, generally manufactured by a dental technician or sometimes produced chairside as a CAD/CAM restoration (e g, Cerec; Siemens, Bensheim, Germany). However, all indirect esthetic restorations need to be inserted into the cavity preparations by means of a resin-based cement, which bonds to the undersurface of the conditioned restoration as well as to the prepared tooth surface. The bond to the tooth is mediated by an adhesive system, which is applied after conditioning enamel and dentin with the acid-etch technique (total etch). Many of these current bonding agents contain organic acids in their formulations, like maleic acid, or possess acidic-modified monomers (e g, PENTA). This enables them to partially dissolve inorganic tooth structure and modify the smear layer if the dentin is not pre-etched with phosphoric acid (Jacobsen & Finger, 1993). The purpose of the low-viscosity adhesive systems is to penetrate into the decalcified tooth structure and form a micromechanical retention by formation of resin tags into the enamel etch pattern and open dentin tubules and to hybridize the collagenous network of the dentin (Pashley & Carvalho, 1997; Van Meerbeek & others, 1992, 1993; Nakabayashi, Ashizawa & Nakamura, 1992; Gwinnett, 1993). Thus the surface of the hydrophilic dentin is altered, which allows the attachment of a hydrophobic composite resin. This technique has proven successful and is standard procedure in adhesive dentistry.

Black (1945) introduced the first air-abrasion unit for nonmechanical cavity preparation and prophylaxis as a result of his studies beginning in early 1943. The basic principle of these devices, beginning with the first available unit up to today's sophisticated devices, is the utilization of the kinetic energy of a well-defined, sharply focused stream of tiny aluminum oxide (Al_2O_3) particles propelled by high-velocity air pressure (Black, 1945, 1950, 1955; Laurell & Hess, 1995). The kinetic energy of the accelerated particles results in a rapid substance removal when they impact on the tooth surface. Based on this physical law, the technique is also called "kinetic cavity preparation" (KCP). Air abrasion is promoted for effective cavity preparation and also for alternative conditioning of enamel and dentin surfaces in lieu of acid etching in adhesive procedures prior to the application of an adhesive system (Bae & others, 1996; Berry & Ward, 1995; Doty & others, 1994). Air abrasion provides a rough irregular surface with large surface area and increases its wettability for the adhesive system (Eakle, Wong & Huang, 1995; Gwinnett & Berry, 1996; Los & Barkmeier, 1994; Roeder & others, 1995). It is also a helpful preparation technique for the treatment of pediatric or anxious patients, for during preparation no pressure, heat, vibration, or unpleasant sounds occur as encountered when using rotary instrumentation (Clinical Research Associates Newsletter, 1996; Black, 1945, 1950, 1955; Goldstein & Parkins, 1994; Laurell & Hess, 1995; Morrison & Berman, 1953; Goto & Zhang, 1996). Therefore, in many cases there is no need for local anesthesia (Berry & Ward, 1995; Goldstein & Parkins, 1994; Morrison & Berman, 1953; Goto & Zhang, 1996). All of these are major factors in minimizing patients' discomfort. An inquiry of Goldberg (1952) about patients' reactions to air abrasion revealed that of a total of 1141 exposed patients, 92.3% preferred air-abrasion technology for future dental treatment. Of the 49.7% of all patients who felt pain, 81.7% indicated the pain was mild.

After initial success the air-abrasive technique disappeared by the late 1950s and early 1960s, due to the introduction of the much less expensive high-speed handpieces, which were better suited for amalgam and gold restoration preparations (Berry & Ward, 1995; Franetzki, 1993; Goldstein & Parkins, 1994; Laurell & Hess, 1995). However, the availability of modern adhesive restorative materials, such as dentin adhesive systems, composite resins, low-viscosity flowable composite resins, pit and fissure sealants, and the development of minimally invasive preparation techniques reduced the need for precise cavity outlines to achieve retention. These events led to a resurrection of highly improved modern air-abrasion units from different manufacturers during the early 1990s (Bae & others, 1996; Berry & Ward, 1995; Franetzki, 1993; Goldstein & Parkins, 1994; Laurell & Hess, 1995).

There are contradictory statements in the scientific literature as to whether acid conditioning of the air-abraded tooth surface can be omitted or not. Some research groups showed the need for subsequent acid etching of the dentin, if optimum bond strength and cavity sealing were desired. Roeder and others (1995) reported that acid etching of enamel and priming of the dentin were necessary to achieve maximum bond strengths to air-abraded tissues. Berry, Berry, and Powers (1994) showed significantly higher bond strengths of hybrid ionomers to air-abraded enamel

and dentin when additional conditioning with 10% polyacrylic acid was carried out. Tensile bond strengths of resin composite to air-abraded, acid-etched enamel were significantly greater than were those to air-abraded, unetched enamel (Berry & Ward, 1995). Bae and others (1996) measured the shear bond strength of composite to various surfaces and described the conditioning of enamel and dentin with air abrasion as less effective than acid etching. In their evaluation of an air-abrasion preparation system for bonded restorations, Valentino and Nathanson (1996) concluded that this technique could be effective for dentin bonding when used in conjunction with acid etching, but it could not be used as a sole surface treatment prior to bonding composite to enamel or dentin. Ploeger and others (1996) compared the enamel bond strengths of four different air-abrasion units using different powder and air-pressure settings. Air abrasion only resulted in significantly lower values than acid etch only; the latter again yielded significantly lower bond strengths than air abrasion plus additional etching. Horgesheimer and others (1995) found a significantly lower shear bond strength of composite to enamel if the surface was only prepared with air abrasion, then acid etched with 37% H_3PO_4 for 30 seconds. In a microleakage analysis of pit and fissure sealants, Haws and others (1996) revealed that acid etching alone or in combination with previous air abrasion was a better option than air abrasion alone to prevent sealant leakage.

Other studies showed that air abrasion alone yielded results equal or even superior to acid etching. A comparison of the microleakage of class 5 composite fillings of air-abrasive prepared cavities and those prepared with a bur and subsequent etching with 37% phosphoric acid for 30 seconds showed no significant difference between the treatment methods (Keen, Parkins & Crim, 1995). Laurell, Lord, and Beck (1993a) reported no significant difference in the shear bond strength to enamel between an acid-etched and an air-abraded surface at 160 psi air pressure. In the same study, the use of a dentin primer did not improve the bond strength of composite to air-abraded dentin. In another study, Laurell, Dodd, and Johnston (1993b) obtained significantly higher shear bond strengths for dentin surfaces air abraded with 50 μm particles at 160 psi compared to specimens phosphoric acid etched for 30 seconds. Keen, von Fraunhofer, and Parkins (1994) obtained similar shear bond strengths to air-abraded and to acid-etched enamel (35% H_3PO_4). However, the dentin bond strengths obtained with an air-abrasive pretreatment were significantly higher compared to etched dentin. Considering the results of their investigation about enamel etching abilities, Doty and others (1994) concluded that air-abrasion technology had the potential to prepare enamel bonding surfaces equal to those obtained from acid etching. Laurell and Hess (1995) stated that the microscopic roughness of air-abraded human enamel and dentin resulting from an abrasive treatment with 27 μm alumina particles at 160 psi was suitable for resin retention without acid etching.

This study concentrated on the effects of air abrasion on the in vitro bond strength of a composite resin to moist and dry dentin and compared those to acid-etched dentin, as well as to a combination of both treatments. Furthermore, the quantitative and qualitative effects of different powder and air pressure adjustments were determined.

Table 1. Dentin Treatment Procedures--Experimental Groups (N/A = Not Applicable)

Surface Finish	Al_2O_3 Particle Size (μm)	Air Pressure (psi)	Acid Etch (37% H_3PO_4 for 20 seconds)	Dentin Surface (moist/dry)
500-grit SiC	N/A	N/A	no	moist
500-grit SiC	N/A	N/A	no	dry
500-grit SiC	N/A	N/A	yes	moist
500-grit SiC	N/A	N/A	yes	dry
Air abrasion	50	120	no	moist
Air abrasion	50	120	no	dry
Air abrasion	50	120	yes	moist
Air abrasion	50	120	yes	dry
Air abrasion	50	160	no	moist
Air abrasion	50	160	no	dry
Air abrasion	50	160	yes	moist
Air abrasion	50	160	yes	dry
Air abrasion	27	160	yes	dry

METHODS AND MATERIALS

Specimen Preparation for Shear Bond Strength

Two hundred sixty freshly extracted caries-free human molars of the permanent dentition, stored in a 0.25% mixture of sodium azide in Ringer solution until the date of use, were randomly divided into 13 groups of 20 teeth each. After embedding the teeth in a self-curing acrylic resin (Technovit 4004; Heraeus Kulzer, Wehrheim, Germany), flat occlusal surfaces of superficial dentin were exposed by cutting the crown segments with a water-cooled diamond saw (Varicut; Leco, Kirchheim, Germany). A defined smear layer was produced by grinding the dentin with wet silicon carbide paper from 240- to 500-grit on a polishing machine (Automet Grinder; Buehler Ltd, Lake Bluff, IL 60044).

Treatment categories were based on dentin surface conditioning. The different treatment groups included in this study are listed in Table 1. Dentin surfaces prepared with 500-grit SiC paper served as controls. The other specimen surfaces were subsequently air abraded for 6 seconds by means of a KCP 1000 Whisperjet unit (American Dental Technologies, Southfield, MI 48034) with 50 µm or 27 µm aluminum oxide particles at 120 or 160 psi air pressure respectively. Attention was directed to condition the dentin evenly with the alumina powder for all specimens, with six overlapping horizontal passes and six overlapping vertical passes. The distance of the nozzle tip to the dentin surface was 5 mm, and the nozzle was held perpendicular to the dentin surface. After abrasion the specimens were thoroughly rinsed with vigorous waterspray for 30 seconds to clean the surfaces of residual alumina particles. Half of the groups were then additionally etched with 37% phosphoric acid (Email Preparator GS, Batch No 823188; Vivadent, Schaan, Liechtenstein) for 20 seconds and thoroughly rinsed. Bonding area was defined by a punched Mylar matrix (diameter 2.5 mm) on top of the conditioned dentin. Corresponding to the treatment groups the dentin was either dried with oil-free air for 5 seconds so that the surfaces were visibly dry, or the dentin was remoistened with a wet cotton pellet, yielding a visible moist surface. Immediately following, the dentin adhesive system Syntac Single-Component (Batch No 815324, Vivadent) was applied according to the manufacturer's instructions.

Cylinders of Tetric composite (Batch No 813181, Vivadent) with a bond diameter of 2.5 mm and a height of 3.0 mm were bonded to the dentin in two increments using a split polytetrafluoroethylene mold that was lined up with the Mylar matrix opening. Each increment of composite was individually light cured for 40 seconds with a Translux CL curing unit (Heraeus Kulzer). The light output of the curing unit was monitored with a light meter (Curing Radiometer Model 100; Demetron Research Corp, Danbury, CT 06810).

The specimens were stored in Ringer solution for 24 hours at 37° C and then subjected to thermocycling for 1000 cycles between 5° C and 55° C water, with 30 seconds of dwell time in each bath and a transfer time of 5 seconds. Shear bond strengths were determined using a Universal Testing Machine (QTS 2000; Quicktest, Haan, Germany) at a crosshead speed of 0.5 mm per minute by placing a chisel-shaped rod immediately adjacent and parallel to the adhesive interface between the composite and the dentin. Bond strengths in MPa were calculated by dividing the maximum force at failure by the bonded area.

The failure sites of the debonded specimens were examined at X40 magnification in a dissecting microscope. A videocamera connected to a personal computer with a frame-grabber card was mounted on the microscope to transfer the image to the computer to determine and quantify the type of bonding failure. Quantitative analysis of the image of the bonding site was done by means of an image-processing software (Tiff-Mess; Stefan Kueppers, Erlangen, Germany). Differentiations in percent of the bonded area were made as follows: a = adhesive fracture at the bonded interface; b = cohesive fracture in dentin; c = cohesive fracture in the composite.

Statistical Analysis

Means and standard deviations were determined from 20 replications for each treatment group. Data

Table 2. Shear Bond Strengths (MPa). Mean of 20 Replications Per Group with Standard Deviations in Parentheses

	No Air Abrasion		Air Abrasion				
			50 µm Al_2O_3				27 µm Al_2O_3
			120 psi	120 psi	160 psi	160 psi	160 psi
Dentin	no acid etch	acid etch	no acid etch	acid etch	no acid etch	acid etch	acid etch
Moist	8.3 (4.7)	15.4 (2.1)	18.3 (6.3)	15.6 (4.4)	21.6 (6.4)	17.1 (3.7)	------
Dry	10.8 (3.2)	13.2 (5.1)	15.9 (4.6)	16.2 (4.8)	18.4 (3.6)	23.9 (5.2)	21.8 (5.0)

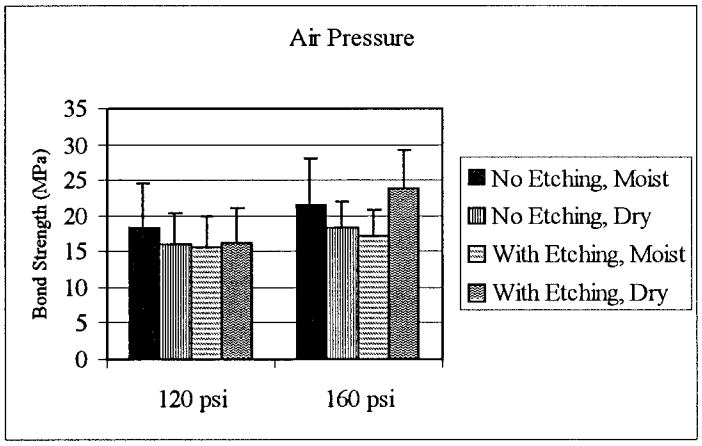

Figure 1. *Bond strength (MPa) of air-abraded dentin specimens with 50 μm aluminum oxide particles and 120 psi vs 160 psi air pressure*

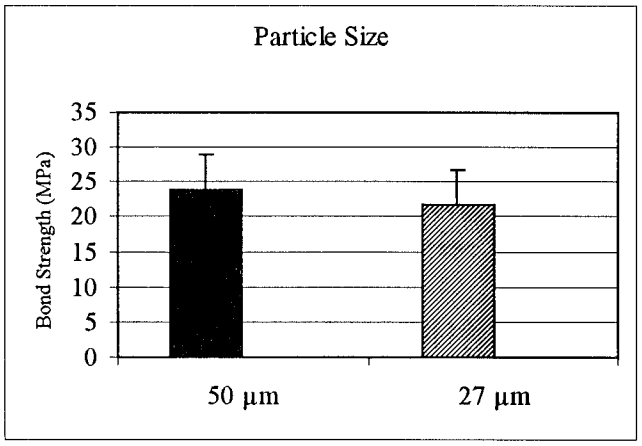

Figure 2. *Bond strength (MPa) of air-abraded dentin specimens with 160 psi air pressure and 27 μm vs 50 μm aluminum oxide particles*

were analyzed for normal distribution with the Shapiro-Wilks test and for homogeneity of variances with Levene's test. Then the data were statistically analyzed by three-way analysis of variance (ANOVA) with subsequent post hoc Bonferroni pairwise comparison tests and with the *t*-test (SPSS 6.1.3 for Windows; SPSS Inc, Chicago, IL 60611). The elected level of significance was 0.05. Data of the failure site classification were not examined statistically.

Scanning Electron Microscopy

Scanning electron micrographs were made to examine the effects of the different conditioning methods on the dentin surface. For each kind of pretreatment two teeth were prepared for SEM investigation. Again flat occlusal surfaces of superficial dentin with a defined smear layer were exposed by cutting the crown segments with a water-cooled diamond saw (Varicut). A control surface with a defined smear layer was produced by grinding the dentin with wet silicon carbide paper from 240- to 500-grit on a polishing machine (Automet Grinder; Buehler Ltd). These surfaces were compared to acid-etched and to air-abraded dentin surfaces with different settings of aluminum oxide powder size and air pressure.

Specimens for SEM evaluation were dehydrated in graded ethanol and critical point dried. Then the specimens were mounted on scanning electron microscopy stubs and coated with gold in a sputter coater for 5 minutes (SEM Autocoating Unit E5200; Polaron Equipment Ltd, Watford, England). The specimens were then examined in a scanning electron microscope (Leitz AMR 1200; Leitz, Wetzlar, Germany).

RESULTS

Shear Bond Strength

The mean shear bond strengths in MPa and standard deviations for 20 replications for each condition of bonding Tetric composite to human dentin are presented in Table 2. The preliminary analysis of the data confirmed normal distribution with the Shapiro-Wilks test ($P > 0.05$) and homogeneity of variances with Levene's test ($P > 0.05$) for all groups.

Table 3. Failure Site Analysis in Percent of the Bonded Area

	No Air Abrasion		Air Abrasion				
			50 μm Al_2O_3				27 μm Al_2O_3
			120 psi	120 psi	160 psi	160 psi	160 psi
Dentin	no acid etch	acid etch	no acid etch	acid etch	no acid etch	acid etch	acid etch
Moist	a = 100%	a = 80% b = 20%	a = 79% b = 21%	a = 82% b = 18%	a = 74% b = 26%	a = 67% b = 33%	------- -------
Dry	a = 100%	a = 96% b = 4%	a = 87% b = 13%	a = 69% b = 31%	a = 91% b = 9%	a = 58% b = 42%	a = 73% b = 27%

a = adhesive fracture; b = cohesive fracture in dentin; c = cohesive fracture in composite.

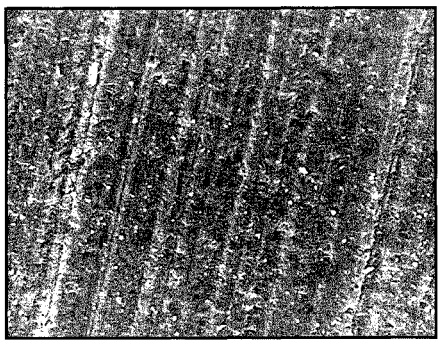

Figure 3. *Smear layer on dentin surface, created by wet grinding with SiC paper to 500-grit. Tracks of the grinding are clearly visible (original magnification X500).*

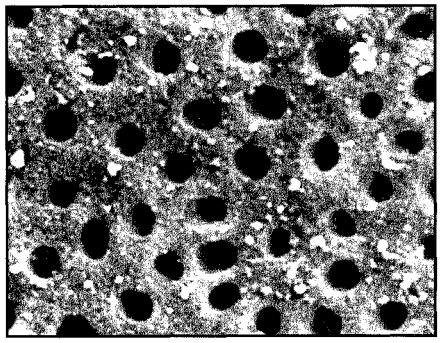

Figure 4. *Dentin acid etched with 37% H_3PO_4 for 20 seconds. Smear layer is completely removed and tubules are widely open. Surface is slightly contaminated with silica particles (original magnification X1000).*

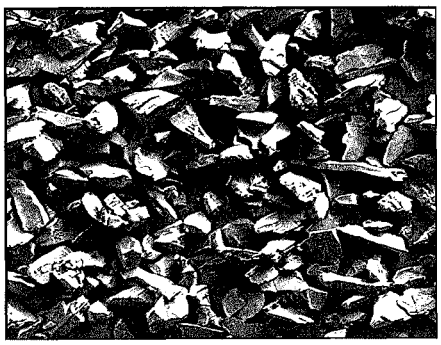

Figure 5. *50 µm aluminum oxide air-abrasive powder. Particles have a polymorph and sharp-edged shape (original magnification X75).*

Three-way ANOVA for the factors--air-abrasive pretreatment (yes vs no), etching with phosphoric acid (yes vs no), and surface condition (moist vs dry)--showed significantly higher bond strengths for air-abraded specimens ($P = 0.001$). Both other factors had no significant influence on the results, with $P = 0.112$ for acid etching and $P = 0.628$ for surface conditions. Lowest bond strengths were obtained in moist and dry groups without conditioning the dentin, i e, dentin ground to 500-grit without acid etching. All other etched groups and air-abraded groups, without and with subsequent acid etching, showed significantly higher bond strengths ($P < 0.05$), as obtained by post hoc multiple pairwise comparisons with the Bonferroni test. Under dry bonding conditions, the air-abraded groups showed at 160 psi (without and with subsequent acid etching) significantly higher bond strengths than at 120 psi for the etched-only group. Generally, air abrasion yielded higher bond strength values of composite to dentin than nonabraded groups. However, these differences were only statistically significant for unetched nonabraded groups, and etched nonabraded specimens compared to groups abraded with 160 psi air pressure and bonded to a visibly dry dentin surface ($P < 0.05$).

A three-way ANOVA conducted only for the groups pretreated with 50 µm aluminum oxide particles at 120 and 160 psi air pressure (Figure 1) respectively revealed significant differences between the two different settings in favor of the higher air pressure ($P = 0.003$). There were again no significant differences between acid etching the dentin after air abrasion versus no etching ($P = 0.726$) and between moist versus dry conditions of the dentin surface prior to the application of the adhesive system ($P = 0.617$).

The *t*-test for independent samples was applied to determine the influence of a pretreatment with 50 µm versus 27 µm aluminum oxide particles at 160 psi followed by 20 seconds etching with 37% H_3PO_4

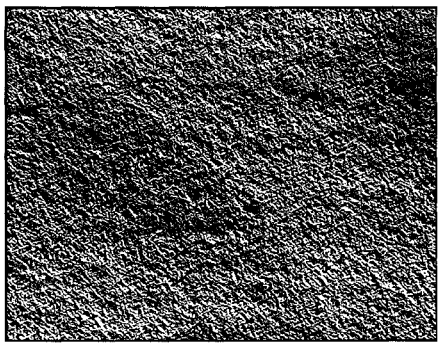

Figure 6. *Irregular dentin surface created by air abrasion with 50 µm particles and 120 psi pressure. A slightly wave-like surface is observed (original magnification X55).*

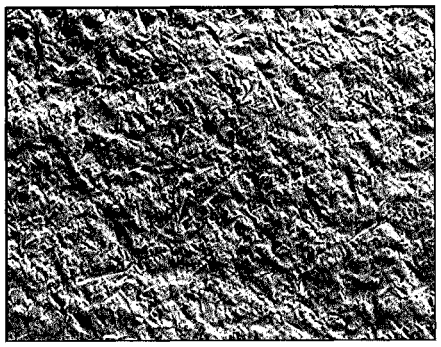

Figure 7. *A higher magnification of the surface, created by air abrasion with 50 µm particles and 120 psi pressure, shows clearly the rough dentin surface. No open tubules can be seen (original magnification X175).*

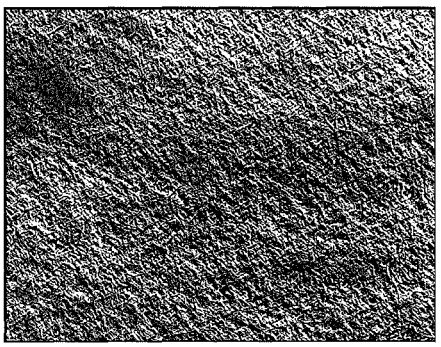

Figure 8. *Irregular dentin surface created by air abrasion with 50 µm particles and 160 psi pressure. A more distinct wave-like surface with larger surface area is observed (original magnification X55).*

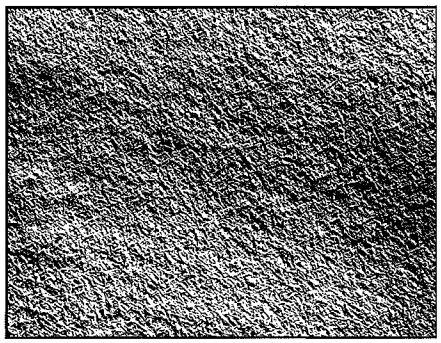

Figure 9. *Irregular dentin surface created by air abrasion with 27 µm particles and 160 psi pressure. The surface morphology looks identical to an abrasion with 50 µm particles and 160 psi pressure (original magnification X55).*

(Figure 2). No statistically significant difference (P = 0.290) could be determined for the bond strengths generated by different powder sizes.

The results of the examination and quantification of the failure sites are shown in Table 3. Unetched 500-grit control groups debonded to 100% adhesively at the interface between the dentin and resin composite. Acid etched-only groups yielded 80 to 96% adhesive failures, whereas air abrasion with aluminum oxide particles increased the number of cohesive failures in dentin in a range from 13 up to 42%. In one air-abraded group 9% cohesive fracture occurred in the composite material.

Scanning Electron Microscopy

The qualitative comparison of the various pretreatment methods to condition the dentin surface prior to application of the adhesive system Syntac Single-Component revealed distinct differences in the surface texture and morphology of the specimens.

A control surface with a defined, typical smear layer produced by grinding the dentin with wet silicon carbide paper from 240- to 500-grit on a polishing machine is shown in Figure 3. The smear layer covered the whole underlying dentin and sealed the tubules with smear plugs. Tracks from the grinding procedure are clearly visible. Figure 4 depicts the result of treating a flat ground 500-grit surface with 37% phosphoric acid (Email Preparator GS; Vivadent) for 20 seconds. The smear layer was completely removed, and the lumina of the dentin tubules were widely opened. No smear plugs were observed, thus leading to maximum dentin permeability. The surface was slightly contaminated with small particles, which seemed to be a residue of the etching process. It was probably a precipitate of silica dioxide, which is added to the etchant by some manufacturers to thicken the gel and improve the consistency (Perdigao, Denehy & Swift, 1994).

Aluminum oxide powder particles of 50 µm, the conditioning agent of the air abrasion unit, are shown in Figure 5. The particles have a polymorph and sharp-edged shape, and their size is not uniform. Particles of 27 µm differ only in size to the 50 µm powder but show the same characteristics for the rest. The impact of these particles, highly accelerated by compressed air, on the dentin yielded a very irregular surface morphology. The scanning electron micrograph in Figure 6 is a result of conditioning the dentin with 50 µm Al_2O_3 particles at 120 psi air pressure. The abrasive pretreatment roughened the dentin surface clearly and generated a wave-like surface, thus increasing the surface area. The surface was covered with a smear layer, and no open dentin tubules could be seen. This observation was confirmed by the analysis of a higher magnified part of this surface (Figure 7). Dentin debris occluded the openings of the tubules and covered the peri- and intertubular dentin. No remnants of the alumina particles were clearly identified on the rough and irregularly furrowed surface. Alumina particles of 50 µm propelled by 160 psi air pressure (Figure 8) yielded a more distinct wave-like surface with larger differences in altitude between the highest part at the ridges and the lowest parts at the bottom than that obtained by 120 psi air pressure, thus leading to a higher increase in surface area compared to the lower pressure setting. The other characteristics of the 160 psi abraded dentin surface were very similar. The surface morphology and the increase of surface area created by 27 µm alumina particles at 160 psi air pressure (Figure 9) looked identical to the results of the 50 µm powder treatment at the same pressure.

DISCUSSION

Bonding of resin composite to dentin and enamel is a crucial element of modern state-of-the-art dentistry. At least concerning the dentin, the reliability and durability of the adhesively bonded interface still needs to be improved. Researchers in the laboratories of dental manufacturers and universities utilize in vitro tests to determine or confirm the effectiveness of new restorative techniques and materials before these are applied to the patient. The measurement of microleakage or bond strength is a common procedure to evaluate the performance of dentin adhesive systems or the effectiveness of different etching and conditioning procedures (Jacobsen & Finger, 1993).

Air-abrasive conditioning of hard tooth tissues with tiny aluminum oxide particles is controversial. To obtain optimum results, subsequent etching of enamel and dentin with phosphoric acid is advocated by several authors (Bae & others, 1996; Haws & others,

1996; Valentino & Nathanson, 1996). Modern adhesive dentistry allows in many cases the utilization of minimally invasive air-abrasion technology for preparation as the need for precise cavity outlines to achieve retention is reduced (Goldstein & Parkins, 1994). It would be a great advantage in time and handling if the additional step of acid etching could be omitted after completion of the cavity preparation with air abrasion. Of course, the quality of the adhesion of the restorative material to the tooth substance and the seal of the cavity should not be negatively affected. It would be highly desirable if clinically acceptable bond strengths could be obtained without acid etching (Parkins, 1996). Different reports in the literature support the success of air-abrasive etching as a sole measure in conditioning enamel and dentin (Doty & others, 1994; Keen & others, 1994; Laurell & others, 1993a).

When tooth surfaces are treated by rotary instruments or air abraded, a layer of resultant debris is deposited on the surface. This smear layer is resistant to mechanical removal and can only be removed by chemical means (Berry, von der Lehr & Herrin, 1987). A mechanical approach to remove it produces only a finer smear layer. We observed that all different powder and air pressure settings of the KCP 1000 unit created a smear layer on the surface of the air-abrasive-treated dentin and sealed the tubules. These observations were confirmed by a qualitative SEM study, showing the openings of the dentin tubules to be blocked by debris (Laurell & Hess, 1995; Los & Barkmeier, 1994). The cutting characteristics and the obliteration of the tubules seem to be dependent on the exposure time to the alumina particles (Parkins, 1996). A short burst of powder stream leaves many tubules open, whereas longer periods seal the surface (Bester & others, 1995). Gwinnett and Berry (1996) found no surface debris and no plugs in the open tubules after conditioning the dentin with air abrasion; however, the size of the particles used in this study was not reported. In accordance with Laurell and Hess (1995) and Katora, Jubach, and Polimus (1981), we could not observe residual aluminum oxide particles after vigorously cleaning the abraded surface with waterspray.

Dentin bond strengths with air abrasion can be higher than specimens etched with phosphoric acid (Keen & others, 1994; Laurell & others, 1993a). The wettability for the dentin adhesive seems to be enhanced by air abrasion (Los & Barkmeier, 1994; Roeder & others, 1995). Keen and others (1994) reported stronger bonds for high-pressure abraded dentin specimens than with low pressure. In our study, we could observe this effect as well. The impact of uncountable high-energetic alumina particles on the dentin leads to a characteristic, very rough and irregular surface with large and increased surface area (Bester & others, 1995; Eakle & others, 1995; Gwinnett & Berry, 1996; Los & Barkmeier, 1994). This effect was more distinct with 160 psi air pressure than the 120 psi setting. Due to the higher kinetic energy of the particles propelled by 160 psi, the wave-like surface was clearer and the abrasive particle stream was more effective (Manhart & others, 1997). Thus a higher increase in surface area for bonding was created, leading to significantly higher bond strengths for the 160 psi abraded specimens compared to 120 psi adjustment. The increase in surface area after air abrasion accounts for the increase in bond strength (Los & Barkmeier, 1994). Bond strength with air abrasion seems to be primarily related to the air pressure, i e, to the kinetic energy of the particles. With lower air pressure, (subsequent) acid etching of the abraded tooth surface appears to be clinically important (Parkins, 1996). The rough surface after air-abrasive treatment seems to provide additional mechanical retention to the adhesive system similar to etched enamel.

The size of the aluminum oxide particles has no significant influence on the resulting bond strength (Keen & others, 1994; Ploeger & others, 1996). There were no statistical differences in the shear strengths between 50 μm (23.9 MPa) and 27 μm Al_2O_3-particles (21.8 MPa), both propelled by 160 psi pressure. The SEM micrographs showed an identical surface morphology and increase of surface area for both powder sizes.

Most dentin adhesive systems use an acid to condition the dentin surface prior to their application. The acid, in most cases 35-37% H_3PO_4, removes the smear layer, opens the dentin tubules with simultaneous increase of the dentin permeability, and dissolves inorganic hydroxyapatite crystals of the dentin structure, thus leaving primarily a three-dimensional network of collagen fibers on the deeper unaltered dentin surface. Low-viscosity monomers of the adhesive system infiltrate this porous collagen-rich dentin surface and form a resin-dentin hybrid layer (Van Meerbeek & others, 1992, 1993). When the smear layer is not removed by a total-etch technique, it needs to be modified to allow sufficient and durable adhesion of the resin. The comparison of etched and nonetched air-abraded dentin specimens in this study showed no statistically significant differences in bond strength. The maleic acid in the formulation of Syntac Single-Component is capable of self-etching and partially dissolving the smear layer while the monomers penetrate into the collagen network. This is obviously the reason for bond strength values of 8.3 to 10.8 MPa even in the nonconditioned control groups. Parts of the dissolved smear layer are blown away when drying the first layer of adhesive, the rest reprecipitates and is

included in the light-cured bonding layer. It is questionable if these favorable results can also be obtained with adhesives that are not self-etching and therefore may be incapable of allowing a sufficient modification of the smear layer. This study measured the bond strength after 24 hours of storage of the specimens in Ringer solution. However, it is of interest to know if the bond strengths could be maintained over longer time periods, as little is known about the special composition of the smear layer generated by air abrasion and its attachment to the underlying unaltered dentin. Further studies are necessary to clarify the effect of this smear layer and long-term storage on the bond strength of composite to air abraded dentin.

Bond strengths are also dependent on the moisture content of the demineralized dentin (Pashley & Carvalho, 1997). A desiccated dry dentin surface results in a collapse of the collagenous network with compromised bond strength, as the resin monomers cannot completely penetrate this dense layer. However, air drying the dentin surfaces prior to the application of Syntac Single-Component did not result in a significant difference in the bond strength. This water-based system possesses the ability to re-moisten the collagen and allows the re-expansion of the collagen fibers to facilitate sufficient penetration of the adhesive monomers to create an effective hybrid layer.

CONCLUSIONS

The results of our study, which measured the bond strength of composite to air-abraded and to acid-etched dentin under dry and moist surface conditions, showed that air abrasion as the only conditioning treatment, in conjunction with a self-etching, maleic acid-containing dentin adhesive system (Syntac Single-Component), was capable of providing bond strength values equal or even higher than a conventional treatment with 37% H_3PO_4 for 20 seconds. The size of the aluminum oxide particles had no influence on dentin bond strength, whereas 160 psi air pressure yielded significantly higher results than 120 psi. Air abrasion produced a rough, irregularly structured surface morphology, thereby increasing the surface area.

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Marginal Adaptation of Heat-pressed Glass-Ceramic Veneers to Class 3 Composite Restorations in Vitro

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Clinical Relevance
Class 3 composite restorations did not significantly influence the marginal adaptation of adjacent ceramic veneers.

SUMMARY

The aim of the present in vitro study was to compare the marginal adaptation and integrity of heat-pressed glass-ceramic veneers to adjacent class 3 composite restorations and to enamel using four dual-curing composite resin cements of different viscosity with their corresponding dentin bonding agents. Thirty-six caries-free human maxillary incisors were first restored with mesial and distal class 3 composite restorations and then prepared for facial ceramic veneers. The cavity margins of the veneers were located either in the class 3 composite restorations or in the residual enamel. Heat-pressed glass-ceramic veneers (IPS Empress) were inserted adhesively using one of the following four luting systems in nine teeth: SonoCem (SC) with EBS; Variolink Ultra (VU), Variolink High-Viscosity (VHV), and Variolink Low-Viscosity (VLV) with Syntac. The veneer margins in the region of the composite restoration and in the region apical to the composite restoration (ceramic/composite resin cement interfaces, composite resin cement/composite restoration interface, and composite resin cement/enamel interface) were evaluated before and after thermocycling and mechanical loading (TCML) by quantitative margin analysis under a scanning electron microscope (SEM) using an image analysis system. Furthermore, microleakage was assessed in each tooth by dye penetration after TCML. For all luting systems, SEM analysis revealed excellent marginal adaptation of the ceramic veneers to the composite restorations as well as to enamel. The median percentages of marginal gap formation were 1.1% and less before TCML and 5.1% and

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less after TCML. The error-rates method revealed no statistical influence of the interface or of the viscosity of the luting material. Maximal values of dye penetration showed a significantly higher microleakage at veneers cemented with VU (median: 86.4%) compared to SC (median: 13.3%). In conclusion, the present data demonstrated that existing clinically acceptable class 3 composite restorations have no negative influence on the marginal adaptation of ceramic veneers. This was valid independent of the viscosity of the dual-curing composite resin cement when SC, VHV, or VLV was used.

INTRODUCTION

The therapy of defective and discolored anterior teeth has always been a challenge for the restorative dentist. While well-designed crowns can provide excellent esthetic results, an adequate preparation is often very destructive with regard to the removal of sound tooth substance and the risk for pulpal and periodontal involvement. As a more conservative and highly esthetic alternative, ceramic veneers are able to mask discolored teeth and to restore fractured, malformed, or malaligned anterior teeth (Calamia, 1985, 1989; Chalifoux, 1994; Costello, 1995; Coyne & Wilson, 1994; Dunne & Millar, 1993; Jordan, Suzuki & Senda, 1989; Sheets & Taniguchi, 1990). The recommended superficial and supragingival intraenamel preparation as well as the adhesive luting (Roulet & others, 1989) facilitate a restoration with minimal loss of sound tooth substance and avoid irritation to the pulp and the marginal periodontal tissues (Coyne & Wilson, 1994; Sheets & Taniguchi, 1990). Short- and long-term clinical studies in highly selected patient groups (Calamia, 1989; Coyne & Wilson, 1994; Dunne & Millar, 1993; Jordan & others, 1989) have shown that ceramic veneer restorations with strictly intraenamel preparations are a reliable and effective long-term procedure for the conservative treatment of anterior dentitions, although morphologic examination of the marginal quality using a scanning electron microscope indicated that ideal marginal adaptation is difficult to achieve (Coyne & Wilson, 1994).

So far, ceramic veneers have only been recommended for the restoration of caries-free and restoration-free teeth facilitating intraenamel preparations (Chalifoux, 1994; Costello, 1995; King, 1995; Schmalz, Federlin & Geurtsen, 1994; Sheets & Taniguchi, 1990). However, in reality the clinician often has to face less favorable situations, like existing restorations, interproximal caries, or gingival recessions with exposure of root dentin, which might have a negative influence on the adhesion and retention of the ceramic veneers. According to the presently accepted recommendations, anterior teeth with interproximal lesions (caries, composite restorations) have to be restored either with full-crown restorations or with ceramic veneers that are extended to the lingual surface, including the interproximal lesion, to facilitate intraenamel veneer margins. In the case of class 3 lesions, both treatment methods would result in a significant loss of sound tooth substance. A combination of interproximal class 3 composite restorations covered by a facial ceramic veneer could facilitate an optimal esthetic result, without removing too much sound tooth substance. However, the reduction of the available enamel bonding area might decrease the adhesion of the ceramic veneer (Shaini, Shortall & Marquis, 1997). Forces caused by thermal stress, different coefficients of thermal expansion, and polymerization shrinkage of the composite resin cements could cause failure of the bonding to the composite restorations. So far, there is little knowledge about the influence of existing composite

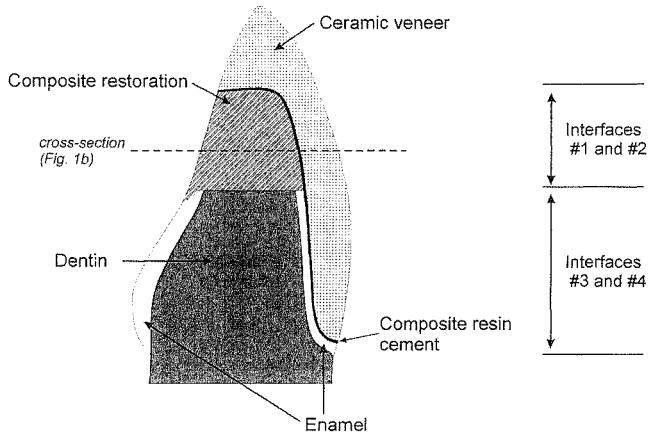

Figure 1A. *Extension of the ceramic veneer and the class 3 composite restoration. The scheme shows the interfaces evaluated by SEM.*

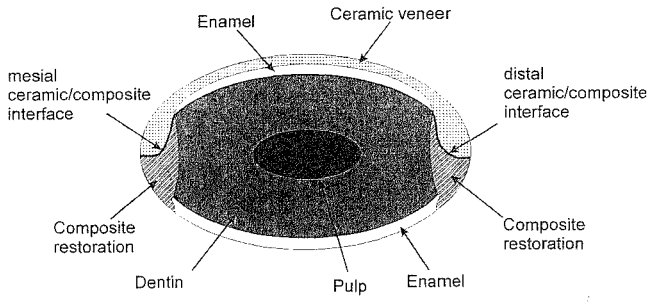

Figure 1B. *Horizontal cross section in the height of the composite restoration (see Figure 1A) showing the interfaces evaluated by dye penetration*

Table 1. Dentin Bonding Agents and Composite Resin Materials for the Interproximal Class 3 Restorations

Group	Dentin Bonding Agent	Chemical Composition (according to manufacturer) % by weight	Batch #	Composite Resin Material (% by volume)	Batch #	Manufacturer
1-4 n = 36	Denthesive II			Charisma filler content: 60%	53	Heraeus Kulzer, Wehrheim, Germany
	Primer A	5% maleic acid, 95% water	33			
	Primer B	82% HEMA, 3.6% methacrylated poly(carbon acid), 3.6% mono(maleic acid)methacryloyloxyethylester, 10% water	39			
	Adhesive Bond II	43.5% BIS-GMA, 48.5% TEGDMA, 7% mono(maleic acid)methacryloyl-oxyethylester	36			

TEGDMA = tri-ethylene-dimethacrylate; BIS-GMA = bisphenol-glycidylmethacrylate; HEMA = 2-hydroxyethyl-methacrylate; n = number of evaluated teeth.

restorations on the marginal adaptation of ceramic veneers. Controlled in vitro or in vivo studies are not available. In two retrospective clinical studies over a period of 5 (Dunne & Millar, 1993) and 6.5 (Shaini & others, 1997) years, increased failure rates were found when veneers were placed on teeth with existing restorations or tooth substance loss. However, neither study gave any information about type, size, quality, age, and localization of the existing restoration.

In ceramic veneers and inlays with margins located either in dentin or enamel, marginal gap formation and microleakage could be reduced in vitro by using highly filled composite resin cements (Christgau & others, 1999; Schmalz, Federlin & Reich, 1995; Thonemann & others, 1994). Theoretically, highly filled composite resin cements show less polymerization shrinkage, which would reduce the stress between veneer and existing composite restoration. On the other hand, inadequate wetting of the ceramic and composite surfaces by a too-viscous composite resin cement would increase the risk of marginal gap formation (Miyazaki & others, 1991; Peutzfeldt, 1994). So far, there is no knowledge in the literature about the influence of the viscosity of composite resin cements on the marginal adaptation of ceramic veneers to existing composite restorations. For this reason, the aim of the present in vitro study was to compare the marginal adaptation of heat-pressed glass-ceramic veneers to adjacent class 3 composite restorations (ceramic/composite resin cement and composite resin cement/composite restoration interfaces) and to the enamel apical to the composite restorations (ceramic/composite resin cement and composite resin cement/enamel interfaces) using four dual-curing composite resin cements of different viscosities with their corresponding dentin bonding agents.

METHODS AND MATERIALS

Preparation and Veneer Fabrication

Thirty-six caries-free human maxillary incisors were stored in a 0.1% thymol solution at room temperature for less than 4 weeks after extraction. Then the teeth were stored in 0.9% saline in a refrigerator (4°C) for at least 1 week. The teeth were scaled, cleaned with pumice, and the apices sealed with gutta percha. The teeth were embedded in a poly(methylmethacrylate) resin (Pattern Resin, GC Dental, Tokyo, Japan) up to 3 mm below the cementoenamel junction (CEJ) in molds matching the clamps of the thermocycling machine.

In the mesial and distal midcoronal surfaces of each incisor, standardized approximal class 3 cavities (Figures 1A & B) were prepared using a cylindrical ISO 012 diamond bur (Brasseler, Lemgo, Germany). The cavity dimensions were produced by the diameter of the bur, resulting in a cavity of about 1.2 mm in an apico-occlusal and a mesiodistal direction. The cavity margins were circularly bevelled (0.5 mm) using a diamond finishing bur (40 µm particle size; Brasseler). The enamel margins were etched with 37% phosphoric acid (MiniTip; ESPE, Seefeld/Oberbay, Germany) for 30 seconds, rinsed with water spray for 30 seconds, and dried thoroughly. After covering exposed dentin surfaces with a dentin bonding agent (Denthesive II; Heraeus-Kulzer,

Table 2. Dentin Bonding Agents and Corresponding Composite Resin Cements for Ceramic Veneer Insertion

Group	Dentin Bonding Agent (Batch #)	Chemical Composition (according to manufacturer) % by weight	Composite Resin Cement % by weight (Batch #)	Insertion Technique
1 n=9	ESPE Bonding System (EBS) (ESPE)		Sono-Cem (SC) filler content: 77.3% (Base + Catalyst 111)	ultrasonic
	Primer (001)	50% HEMA, 10% MMC, 40% water		
	Bond (001)	73% bis-methacrylate, 7% HEMA, 17% MAM, initiators and stabilizers		
2 n=9	Syntac (Vivadent)		Variolink Ultra (VU) filler content: 79% (Base: 660017; Catalyst: 602374)	ultrasonic
	Primer (618657)	25% TEGDMA, 4% maleic acid, 41% di-methyl-ketone, 30% water		
	Adhesive (701046)	35% poly-EGDMA, 10% glutaraldehyde, 55% water		
	Heliobond (613764)	60% BIS-GMA, 40% TEGDMA		
3 n=9	Syntac (same)	same as Group 2	Variolink High-Viscosity (VHV) filler content: 76% (Base: 614052; Catalyst: 616853)	finger pressure
4 n=9	Syntac (same)	same as Group 2	Variolink Low-Viscosity (VLV) filler content: 72% (Base: 614054; Catalyst: 614243)	finger pressure

TEGDMA = tri-ethylene-dimethacrylate; BIS-GMA = bisphenol-glycidylmethacrylate; HEMA = 2-hydroxyethyl-methacrylate; Poly-EGDMA = poly-ethylene-glycol-dimethacrylate; MMC = methacryl-magnesium-chelate; MAM = malonic acid-alkyl-methacylate; n = number of evaluated teeth.

Wehrheim, Germany; Table 1) according to the manufacturer's instructions, all prepared surfaces were coated with an unfilled resin (Adhesive Bond II; Heraeus-Kulzer; Table 1), which was air thinned and light cured for 30 seconds. Then the cavities were filled with three increments of a hybrid composite material (Charisma; Heraeus-Kulzer; Table 1). Each composite increment was light cured for 40 seconds (Heliolux; Vivadent, Ellwangen, Germany). All restorations were finished and polished using finishing diamonds (Composhape; Intensiv, Viganello-Lugano, Switzerland) and flexible polishing disks (Sof-Lex polishing disks; 3M Dental Products, St Paul, MN 55144). Afterwards, the teeth were stored in 0.9% saline at 37 °C for 24 hours.

Thereafter, one clinician prepared all teeth for facial ceramic veneers using diamond burs (Brasseler). First, horizontal depth orientation grooves were made using a specially designed 0.5 mm depth gauge bur (LVS depth cutter No 2; Brasseler), providing a well-defined reduction of the enamel layer. Using a chamfered-end, parallel-sided diamond bur, an even reduction of the facial surface with chamfered finishing lines at all margins was achieved. The incisal edge was reduced and the preparation was extended about 1 mm to the lingual surface (Figure 1A).

Interproximally, the preparation was extended about halfway into the interproximal class 3 composite restorations (Figure 1B). On the facial side, the cervical preparation was positioned 0.5 mm coronally of the cementoenamel junction. All cavity margins were located either in the interproximal composite restorations or in enamel (Figures 1A & B). The cavities were finished using a matching diamond finishing bur (40 µm particle size; Brasseler). Impressions were taken using a polyether material (Impregum; ESPE) and customized plastic trays. Following impressions, the teeth were stored again in 0.9% saline at 37 °C for 24 hours until completion of the ceramic veneers. All veneers were fabricated by one dental technician using a high-strength, fine-grained, and leucite-reinforced, heat-pressed, glass-ceramic material (IPS Empress; Vivadent, Schaan, Liechtenstein) according to the manufacturer's instructions. Because of the in vitro situation, individual coloring was omitted. After drying of the teeth, the veneers were tried in using a low-viscosity silicon-based impression material (Silasoft S; Dentax, Karsruhe, Germany). An evenly thin layer of impression material indicated a clinically acceptable fit of the ceramic surface. Furthermore, the marginal fit of the veneers was checked using a binocular light microscope at X10 magnification. Then the internal surfaces of the veneers were etched with 5% hydrofluoric acid (IPS Etching Gel; Vivadent) for 60 seconds, rinsed with tap water, and air dried. Then the veneers were silanated with a coat of Monobond S (Vivadent).

After thorough cleaning of the teeth, the prepared surfaces were etched with 37% phosphoric acid (MiniTip; ESPE) for 30 seconds, rinsed with water spray for 30 seconds, and dried thoroughly. Then the 36 teeth were randomly assigned to four groups of nine teeth each. In each group of teeth, the ceramic veneers were inserted using one of the following four different dual-curing composite resin cements with their corresponding dentin bonding agents according to the manufacturers' instructions (Table 2): (1) Sono-Cem (SC) with the ESPE Bonding System (EBS); (2) Variolink Ultra (VU) with the Syntac bonding system (Vivadent); (3) Variolink High Viscosity (VHV) with the Syntac bonding system (Vivadent); (4) Variolink Low Viscosity (VLV) with the Syntac bonding system (Vivadent). The dentin bonding agents were applied to all prepared tooth and composite surfaces according to the manufacturers' instructions. Both the cavities and the inner surface of the veneers were then coated with the unfilled bonding resin of the dentin bonding system (Table 2), which was air thinned but not light cured. The dual-curing composite resin cements were applied to the inner surface of the veneers, before the veneers were luted to the cavities. Veneers, which were luted with VHV or VLV, were inserted by finger pressure, while veneers, which were luted with Sonocem or Variolink Ultra, were inserted by the ultrasonic insertion technique (Noack & others, 1992; Peutzfeldt, 1994; Walmsley & Lumley, 1995) using the thixotropy of these highly filled composites. For this technique, an ultrasonic device (Cavitron, Dentsply Cavitron Division, Long Island City, NY 11101) with a specially designed two-arm metal tip, which was covered with a protecting plastic material, was used. Excess resin was removed with a small metal spatula. The free surface of the remaining luting material was covered with a glycerin gel and light cured from the facial, lingual, and approximal sides for a minimum of 40 seconds each (Heliolux, Vivadent, Ellwangen, Germany). The curing light was monitored using a light meter (Cure Rite; Caulk/Dentsply, Milford, DE 19963). The gross composite excess was removed immediately after insertion of the veneers using finishing diamonds (Composhape). Then the specimens were stored in 0.9% saline at 37 °C for 24 hours to improve the degree of polymerization of the chemically activated part of the dual-cured cements and to improve the visibility of subtle composite resin excess. The veneers were finished and polished 24 hours after cementation using finishing diamonds and flexible polishing disks (Sof-Lex). The teeth were stored again in 0.9% saline for 48 hours before further processing.

Thermocycling and Mechanical Loading (TCML)

All teeth were subjected to an alternating thermal cycle of 5°C and 55°C in a thermocycling apparatus for 5000 cycles. The dwell time at each temperature was 30 seconds. During the 5000 thermal cycles, 500,000 mechanical load cycles were performed on the incisal edge in the direction of the tooth axis with a frequency of 1.6 Hz and a load of 72.5 N.

Quantitative Margin Analysis

Before and after TCML, for each tooth mesial and distal impressions were taken using customized trays and a vinyl polysiloxane impression material (Permagum, ESPE). Replications were made using a bisphenol A epoxy resin (Araldit; Ciba Geigy, Wehr, Germany). They were gold sputtered and the integrity of the approximal margins was examined under a scanning electron microscope (Stereoscan 240; LEO Elektronenmikroskopie, Oberkochen, Germany) at X200 magnification. At the mesial and distal surfaces, quantitative margin analysis was performed at the following interfaces (Figure 1A) using an image analysis system (Videoplan; Kontron, Eching, Germany) according to the procedures described by Roulet and others (1989):

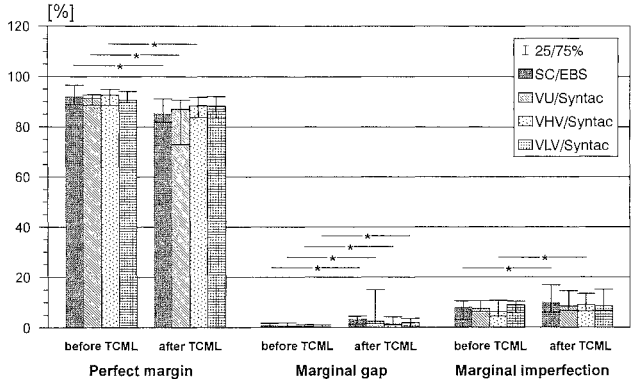

Figure 2. *Quantitative SEM margin analysis of the ceramic/composite resin cement interface in the region of the class 3 composite restoration: median (25/75%) percentages of perfect margin, marginal gap, and marginal imperfection before and after TCML. Significant differences ($P \leq 0.05$) between medians are labelled with star. (SC = Sono-Cem; EBS = ESPE Bonding System; VU = Variolink Ultra; VHV = Variolink High-Viscosity; VLV = Variolink Low-Viscosity).*

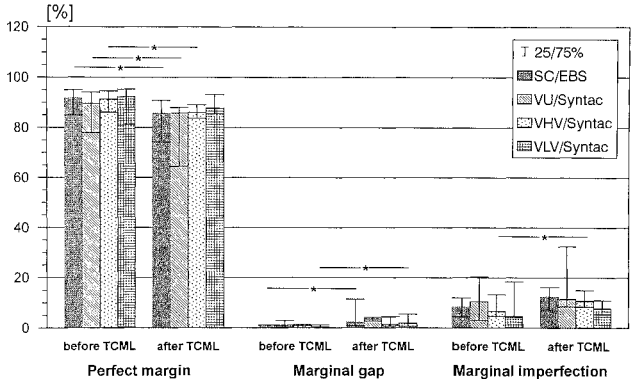

Figure 3. *Quantitative SEM margin analysis of the ceramic/composite resin cement interface in the region apical to the class 3 composite restoration: median (25/75%) percentages of perfect margin, marginal gap, and marginal imperfection before and after TCML. Significant differences ($P \leq 0.05$) between medians are labelled with star. (SC = Sono-Cem; EBS = ESPE Bonding System; VU = Variolink Ultra; VHV = Variolink High-Viscosity; VLV = Variolink Low-Viscosity).*

a) veneer margin in the region of the class 3 composite restoration: interface #1, ceramic/composite resin cement interface and interface #2, composite restoration/composite resin cement interface

b) veneer margin in the region apical to the class 3 composite restoration: interface #3, ceramic/composite resin cement interface and interface #4, composite resin cement/enamel interface.

For each replica side, the specimens were mounted in the SEM using a standardized evaluation angle and a standardized distance from the electron source. The entire visible length of the ceramic veneer margin in the region of the composite restoration and in the region apical to the composite restoration was evaluated (Figure 1A) using the following criteria for the description of the marginal quality: (a) perfect margin—the interfaces under investigation are completely smooth without any interruption of continuity; (b) marginal gap—the interfaces under investigation are separated by a gap caused by adhesive or cohesive failure; (c) marginal imperfection—any kind of incontinuity at one of the interfaces but no marginal gap, e g, marginal ceramic chipping, marginal enamel fracture, overhang, or underfilled margin.

For each tooth, the measured values of the corresponding parameters (entire length of the interfaces under investigation as well as different marginal qualities) of the mesial and distal interproximal surface were added. The lengths of the different marginal qualities were expressed as percentages related to the entire visible length of the related interface.

Dye Penetration

Microleakage was evaluated in all teeth in the region of the composite resin restorations (Figure 1A). For this purpose, after TCML, all tooth surfaces were covered with nail varnish to up to 0.5 mm from the margins between the ceramic veneers and the composite restorations. The facial and lingual margins of the veneer and composite restorations were also covered with nail varnish to prevent interference by dye penetration from these sides. The teeth were stored for 16 hours at 37 °C in a 0.5% basic fuchsin (Fluka, Buchs, Switzerland) solution. Then, in the region of the composite restorations, the teeth were horizontally sectioned (thickness: 350 µm) using a water-cooled low-speed, diamond saw (Microtome 1600; Leitz, Wetzlar, Germany). Per tooth, five to eight sections could be evaluated. Both sides of each section were photographed at X8 magnification. Microleakage between the ceramic veneers and the composite restorations was quantitatively evaluated (Figure 1B) using an image analysis software (Videoplan). For each section, the corresponding measurements of the mesial and distal ceramic/composite interfaces were added. For each tooth, the length of the dye penetration was expressed as percentage related to the entire length of the interface between the ceramic veneer and both composite restorations.

Statistical Analysis

The present study comprised 36 teeth, which were assigned to groups of nine teeth each for testing the

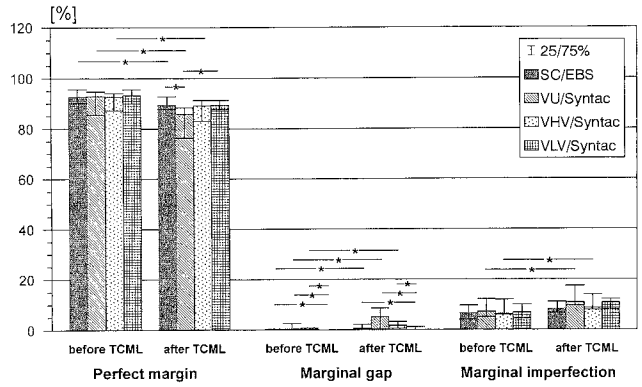

Figure 4. *Quantitative SEM margin analysis of the enamel/composite resin cement interface in the region apical to the class 3 composite restoration: median (25/75%) percentages of perfect margin, marginal gap, and marginal imperfection before and after TCML. Significant differences ($P \leq 0.05$) between medians are labelled with star. (SC = Sono-Cem; EBS = ESPE Bonding System; VU = Variolink Ultra; VHV = Variolink High-Viscosity; VLV = Variolink Low-Viscosity).*

four composite resin cements. For both examination methods (SEM, dye penetration), the median values (with 25/75% percentiles) of nine replications were calculated for each product combination, margin, interface, and time. With regard to microleakage for each single tooth, the maximum dye penetration was found for the five to eight evaluated sections per tooth and was used for further evaluation. Because of the not normally distributed data and varying standard deviations, the statistical analysis was performed using nonparametric tests for pairwise comparisons at a significance level of $\alpha = 0.05$ (SPSS/PC+, Ver. 8.0 for Windows; SPSS Inc, Chicago, IL 60611). The influence of the different composite resin cements was statistically analyzed using the Mann-Whitney-U test, while the Wilcoxon's Signed Rank test was used to test for the influence of TCML and the interfaces. For testing the overall influence of factors, the levels of significance were adjusted to $\alpha^* = 1-(1-\alpha)^{1/k}$ (k = number of performed pairwise tests) using the error-rates method (Miller, 1981).

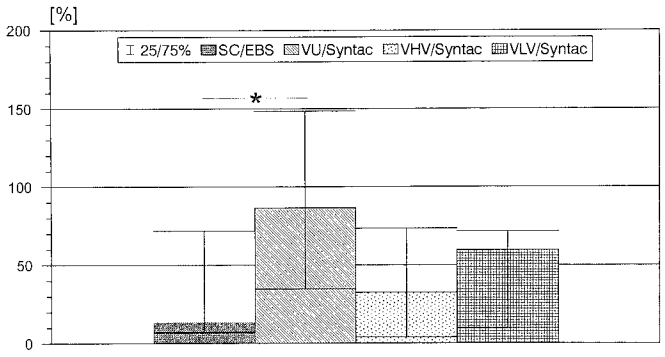

Figure 5. *Dye penetration at the interface between ceramic veneer and class 3 composite restoration: median (25/75%) of the maximum dye penetration (in % of the entire length of the interface between ceramic veneer and class 3 composite restoration) after TCML. (SC = Sono-Cem; EBS = ESPE Bonding System; VU = Variolink Ultra; VHV = Variolink High-Viscosity; VLV = Variolink Low-Viscosity).*

RESULTS

Quantitative Marginal Analysis (SEM)

Figures 2 - 4 show the SEM results and statistical analysis at each evaluable interface before and after TCML.

Interface #1 (Ceramic/Composite Resin Cement Interface in the Region of the Class 3 Composite Restoration; Figure 2)

For all composite resin cements, the median percentages of perfect margins ranged between 90.7 and 92.7% before TCML and between 85.2 and 88.5% after TCML. The decrease caused by TCML was statistically significant for SC, VU, and VHV. While there were less than 1% marginal gaps before TCML, SEM revealed a median percentage of 1.4-3.2% after TCML. TCML caused a significant increase of marginal gap formation for all four composite resin cements. The percentage of marginal imperfections was significantly influenced by TCML for SC and VHV. None of the three marginal qualities revealed any statistical difference among the four composite resin cements, either before or after TCML.

Interface #2 (Composite Restoration/Composite Resin Cement Interface in the Region of the Class 3 Composite Resin)

Due to the lack of any discontinuities and contrast differences, this interface could not be detected by SEM in most of the teeth. For this reason, this interface was excluded from the quantitative evaluation.

Interface #3 (Ceramic/Composite Resin Cement Interface Apical to the Class 3 Composite Restoration; Figure 3)

The median percentages of perfect margins decreased from 89.6-92.3% before TCML to 85.7-87.7% after TCML. The differences caused by TCML were statistically significant for SC, VU, and VHV.

The median percentage of marginal gap formation increased from 0.5-1.1% before TCML to 1.4-2.7% after TCML. This increase was significant for SC and VLV. The percentages of marginal imperfections were significantly influenced by TCML for VHV. At this interface again, no statistically significant differences could be found among the four composite resin cements.

Interface #4 (Enamel/Composite Resin Cement Interface Apical to the Class 3 Composite Restoration; Figure 4)

The median percentages of perfect margins decreased from 92.6 - 93.2% before TCML to 85.8-89.5% after TCML. This difference was statistically significant for SC, VU, and VHV. After TCML, VU revealed significantly less perfect margins than SC and VLV. With 0% marginal gaps before and after TCML, VLV showed significantly less marginal gap formation than the three other composite resin cements (SC, VU, VHV). TCML caused a significant increase of gap formation in SC-, VU-, and VHV-treated teeth. Veneers inserted with VU or VHV showed statistically significant more marginal imperfections after TML.

Statistical analysis applying the error-rates method showed that in general neither the interface nor the viscosity of the composite resin cement had any significant influence on the quality of the marginal adaptation.

Microleakage (Dye Penetration)

The results and statistical analysis of the dye penetration between the ceramic veneers and the class 3 composite restorations are reported in Figure 5. After TCML, VU showed with a median maximum dye penetration of 86.4%, which was more microleakage than SC (13.2%), VHV (32.5%), and VLV (59.6%) showed. The differences between SC and VU were statistically significant. A 75% percentile of 148.5% at veneers cemented with VU indicated that in some teeth dye penetration had passed the ceramic/composite interface up to the ceramic/enamel interface facially of the two class 3 restorations (Figure 1B).

DISCUSSION

Discussion of Methods and Materials

Ceramic veneers, which were adhesively bonded to intraenamel cavities, have shown almost perfect marginal qualities in vitro (Sim & others, 1994; Tjan, Dunn & Sanderson, 1989; Zaimoglu, Karaagaclioglu & Üctasli, 1992) and a high clinical success rate (Dunne & Millar, 1993). If veneers are placed on existing restorations, the available enamel bonding area is reduced (Shaini & others, 1997). Tooth structure and dental restorations are constantly subjected to temperature changes by ingestion of cold and hot beverages and foods. Forces, which are caused by different coefficients of thermal expansion of the different materials (ceramic, composite resin cement, composite restoration) and polymerization shrinkage of the composite resin cement, as well as an insufficient bond strength between the composite resin cement and the composite restoration, could be the main reason for previously observed increased failure rates when ceramic veneers were cemented on existing restorations (Dunne & Millar, 1993; Shaini & others, 1997). The risk for marginal gap formation might be decreased by reducing the polymerization shrinkage using composite resin cements of higher viscosity (Noack & others, 1992; Perdigao & others, 1994; Peutzfeldt, 1994; Walmsley & Lumley, 1995). In the present study, four dual-curing composite resin cements of different viscosities were applied. Besides a low-viscosity composite resin cement (VLV), which is routinely recommended for veneer restorations, composite resin cements (VHV, VU, SC) with higher filler content were used. Two of the latter had to be inserted by the ultrasonic insertion technique (VU, SC). The thixotropic effect of vibrational energy facilitated good flow properties of these highly filled composite resins (Noack & others, 1992; Peutzfeldt, 1994; Walmsley & Lumley, 1995). Theoretically, highly filled composite resin cements show less polymerization shrinkage and better wear characteristics, preventing marginal ditching (Miyazaki & others, 1991; Peutzfeldt, 1994), which might be of importance, especially for the palatoincisal margin of the veneers.

A hybrid composite (Charisma) was used for the class 3 restorations. Although the class 3 composite restorations were placed only a few days before the insertion of the ceramic veneers, any active oxygen-inhibited superficial layer (Rueggeberg & Margeson, 1990) was removed during the polishing of the restorations and the preparation of the veneer cavities. Furthermore, until insertion of the veneers, the teeth were stored in 0.9% saline at 37 °C for 48 hours, simulating aging of the composite restoration in the oral cavity.

As in a previous study (Christgau & others, 1999), a high-strength, leucite-reinforced, heat-pressed, glass ceramic was used for the fabrication of the veneers. The 0.5 mm-thick veneers tolerated the application of the ultrasonic insertion technique without any damage. Similar to the procedure described by Zaimoglu and others (1992), the incisal edge was slightly reduced and the veneer was

extended about 1 mm to the palatal side (Figure 1A). Under clinical conditions, this provides a better possibility to modify the tooth morphology, a more natural translucency of the ceramic, a greater control of the anterior occlusal guidance, and a reduction of the shear forces on the restoration (Harley & Ibbetson, 1991; King, 1995; Sheets & Taniguchi, 1990).

In spite of the fact that the 0.5 mm-thick veneer preparation was located coronally to the cementoenamel junction, dentin bonding agents corresponding to the respective composite resin cements were used. This was in accordance with a previous in vitro study (Nattress & others, 1995) showing a relatively high risk for accidental dentin exposures during veneer preparations, especially at the cervical and approximal margins.

This study should simulate the situation of the oral cavity as closely as possible. For this reason, in contrast to previous investigations (Sim & others, 1994; Tjan & others, 1989; Zaimoglu & others, 1992), thermocycling was combined with mechanical loading, imitating incisal forces, which was already discussed in a previous study (Christgau & others, 1999).

In the present study, the marginal integrity was assessed morphologically by quantitative SEM analysis. Within the limitations of in vitro studies, quantitative margin analysis using SEM has proven to be an exact and reliable method for evaluating the marginal qualities of dental restorations (Peutzfeldt, 1994). All measured parameters describing the marginal quality were expressed as percentages related to the total length of the respective interface, taking into account variations in the size of the teeth and of the restorations. The intraenamel veneer margins located apical to the composite restorations were used as positive controls for the SEM assessment of the interfaces between ceramic and composite restorations.

Furthermore, the marginal integrity was assessed functionally by dye penetration. While in previous studies (Sim & others, 1994; Sorensen & others, 1992; Tjan & others, 1989; Zaimoglu & others, 1992) teeth were cut in only one to three segments, in the present study the evaluation of multiple sections provided more-detailed spatial information about the actual microleakage (Roulet, 1994). Since a restoration is only as good as its worst site, the maximum dye penetration of each tooth was used for further statistical evaluation. Extrapolation of in vitro dye penetration to the clinical situation should be done very carefully. There is some evidence in the literature that in vitro studies are more prone to dye penetration than in vivo studies (Barnes & others, 1993; Castelnuovo, Tjan & Liu, 1996). Penetration into marginal gaps is dependent on molecular size (dye, isotope vs toxin, microorganisms), molecular polarity, surface interaction between dye and restorative material, capillarity, and time (Roulet, 1994). Since in the present study the dye penetration was expressed relative to the total length of the ceramic/composite contact area, the ceramic/enamel interface could not be used as a positive control for the microleakage assessment.

Discussion of the Results

Quantitative SEM analysis revealed similarly favorable marginal adaptations of the ceramic veneers to class 3 composite restorations as well as to enamel located apical to the class 3 restorations. This observation was valid for all four composite resin cements. Due to the lack of any discontinuities or contrast differences, the quantitative evaluation of the composite restoration/composite resin cement interface was impossible in most of the teeth. On the other hand, this can be regarded as an indication of an almost perfect adhesive connection of both composite materials. In bonded veneers, competition may occur between the adhesive forces of the two interfaces. Since the two adhesive forces counteract each other, it is logical that the weaker link may break. If the composite resin cement binds so well to the composite restoration, there could be a risk that the ceramic/composite resin cement interface suffers more from any polymerization shrinkage of the composite resin cement. However, there was no statistical difference between the ceramic/composite resin cement interfaces in the region of the composite restoration or at the interface apical to the composite restorations. All four composite resin cements provided excellent marginal adaptations before and after TCML. At the three quantitatively evaluable interfaces, SEM analysis showed only minimal marginal gap formation with median percentages of 1.1% and less before TCML and of 5.1% and less after TCML. These results confirm findings of previous studies (Sim & others, 1994; Tjan & others 1989; Zaimoglu & others, 1992), which also found excellent marginal adaptation of ceramic veneers to enamel. On the other hand, this study showed again that it is not possible to obtain a hermetically sealed restoration (Van Meerbeek & others, 1998). The good marginal adaptation of ceramic veneers to existing composite restorations is in contrast to previous retrospective long-term clinical studies (Dunne & Millar, 1993; Shaini & others, 1997), which reported an increased failure rate for ceramic veneers that were placed on existing restorations. However, these previous studies gave no information about kind, size, and quality of the existing restorations.

In the present study, no superiority of the higher-filled composite resin cements (SC, VU, VLV) over the low-viscosity cement (VLV) could be found. This is in contrast to previous studies on ceramic veneers

(Christgau & others, 1999) and inlays (Schmalz, Federlin & Reich, 1995; Thonemann & others, 1994) with margins located in dentin or enamel, which showed that highly viscous composite resin cements were statistically more effective in reducing the risk for marginal gap formation.

As already previously shown (Christgau & others, 1999; Stacey, 1993; Thonemann & others, 1994), TCML increased the percentages of marginal gap formation. Although these changes were rather small in the present study, they were statistically significant for all luting cements (SC, VU, VHV, VLV).

The relatively high microleakage values (Figure 5), which were found at the interface between the ceramic veneers and the class 3 restorations, are in contrast to the excellent findings of the SEM analysis (Figure 2). VU especially showed high penetration values, which were significantly higher than the values found for SC. Although SEM did not reveal significantly more gap formation for VU at this interface after TCML than for the other luting cements, the relatively high 75% percentile value of 15% indicated that there might have been problems in some teeth (Figure 2). In the dye penetration data, the 75% percentile of 148.5% at veneers cemented with VU indicated that in some teeth dye penetration had passed the ceramic/composite interface up to the ceramic/enamel interface buccal to the two class 3 restorations. While SEM showed the width of a marginal gap at the surface, dye penetration demonstrated the depth of a marginal gap. The reason for the high microleakage values for VU are not clear. However, it appeared that veneers cemented with VU showed superficially small but deep marginal gaps at the interface between ceramic and composite restoration. SC demonstrated, with a median penetration of 13.2%, the best microleakage results, although the differences demonstrated by VHV and VLV were not statistically significant.

This in vitro study simulated bonding of ceramic veneers to aged composite restorations using different composite resin cements. This situation is similar to the repair of composite restorations using another composite material. Previous in vitro studies (Gregory, Pounder & Bakus, 1990; Kupiec & Barkmeier, 1996; Puckett, Holder & O'Hara, 1991; Turner & Meiers, 1993) have shown good interfacial bond strengths between substrate and repair composite, depending on mechanical roughening of the substrate surface, age of the substrate, filler concentrations, resin formulations, and the viscosity of both the bonding agent and the applied composite resin (Gregory & others, 1990; Powers & others, 1991; Puckett & others, 1991; Turner & Meiers, 1993).

Infrared spectroscopic measurements of residual unreacted double bonds in aged composites (Vankerckhoven & others, 1982) indicated possible chemical bonding between new and old composites. Previous findings (Kupiec & Barkmeier, 1996; Turner & Meiers, 1993) showed that surface roughening was crucial for good interfacial bond strengths. Wetting of the substrate surface by the repair composite is important (Boyer, Chan & Reinhardt, 1984; Gregory & others, 1990; Powers & others, 1991; Söderholm & Roberts, 1991). For this reason, pretreatment with a low-viscosity resin was recommended (Powers & others, 1991). Furthermore, other authors (Puckett & others, 1991; Söderholm & Roberts, 1991) suggested that dentin bonding agents might penetrate cracks in the composite matrix and bind chemically to exposed filler particles of the substrate composite.

These previous findings could explain the good marginal adaptation between composite resin cements and composite restorations found in the present study: using a diamond bur for the veneer preparation removed the superficial layer of the composite restoration, leaving a roughened, not contaminated surface, which was additionally cleaned by acid etching. The interfacial composite bonding was improved by sequential application of a dentin bonding agent and an unfilled bonding resin, before the ceramic veneers were inserted using the composite resin cements. The reasons for the higher microleakage values of VU compared to SC are not known. One might speculate that the increased filler content of VU caused a higher viscosity, resulting in a reduced wetting of the pretreated surface of the composite restoration. Reduced wetting appears to be a more probable reason than differences in the chemistry between the composite restorations and the composite resin cements. VHV and VLV, which have the same matrix composition as VU, did not show significantly more microleakage than SC. This was confirmed by previous findings (Gregory & others, 1990; Pounder, Gregory & Powers, 1987), indicating that interfacial bond strengths are not adversely affected by differences in the composite matrix chemistry.

CONCLUSIONS

Within the limitations of this in vitro study, the present data demonstrated that existing clinically acceptable class 3 composite restorations have no negative influence on marginal adaptation of ceramic veneers. This was valid independent of the viscosity of the dual-curing composite resin cement when SonoCem, Variolink High-Viscosity, or Variolink Low-Viscosity was used.

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CLINICAL ARTICLE

A Method for Mounting Natural Teeth in a Commercial Dentoform

K B FRAZIER • M D DLUGOKINSKI

INTRODUCTION

Before providing patient care, dental students typically practice various procedures on plastic teeth mounted in a typodont or dentoform in the preclinic laboratory. Plastic teeth have been widely accepted by dental educators because of their uniform anatomy, unlimited availability, and ease of replacement into a simulated dental arch. Although artificial teeth have been very useful for preclinical courses, they do not provide the same type of learning opportunities as natural teeth. The student is not afforded the tactile experiences of preparing enamel and dentin with rotary and hand instruments, cannot visualize a dentoenamel junction, cannot gain the full benefits of bonding procedures with resin-based materials, and is unable to finish and polish restorations against natural tooth structure. Infection control concerns and limited availability have probably contributed to a decline in the routine use of natural teeth in preclinical technique courses. However, the use of natural teeth for specific procedures can enhance a dental student's preparedness for patient care.

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Previously, dental educators have attempted to provide realistic restorative dentistry learning experiences by mounting natural teeth in a plaster arch or rigidly in acrylic resin in a dentoform (Clark & Hall, 1969; Warren, 1975; Ireland, Rappold & Capdeboscq 1983; Swift & Khera, 1990). The limitations of these methods include the lack of tooth movement due to the rigid fixation and the difficulties associated with precise positioning of the teeth. An additional problem with custom dentoforms made of plaster or acrylic is the complication in securing the arch to a patient simulator.

PURPOSE

A method of mounting and removing natural teeth in a commercial dentoform will be presented that is quick, neat, and easy. Additionally, the method allows the mounted teeth to be sufficiently mobile to simulate the periodontal ligament so that realistic techniques to obtain approximal restoration contacts can be used. This method allows students the opportunity to practice on natural teeth in their mannequin simulators with many of the related benefits.

DESCRIPTION OF TECHNIQUE

The mounting technique uses polyvinyl siloxane impression material to secure natural teeth to a commercial dentoform. First, selected teeth are removed from the dentoform and disinfected natural teeth are

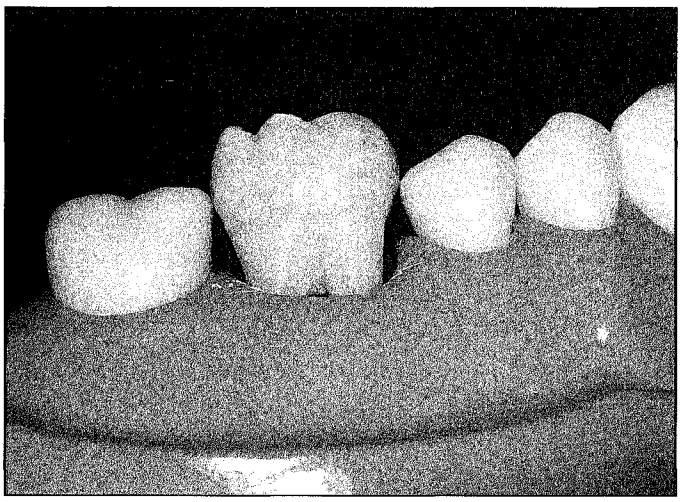

Figure 1. *Appearance of a natural molar that is slightly too large to fit into the socket of commercial dentoform*

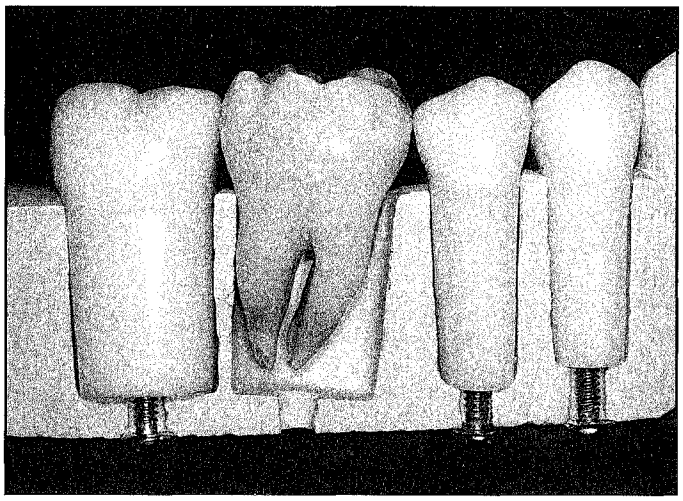

Figure 2. *Cutaway view of a gypsum model of a dentoform shows how approximal contacts and root contours can interfere with complete seating of a natural tooth*

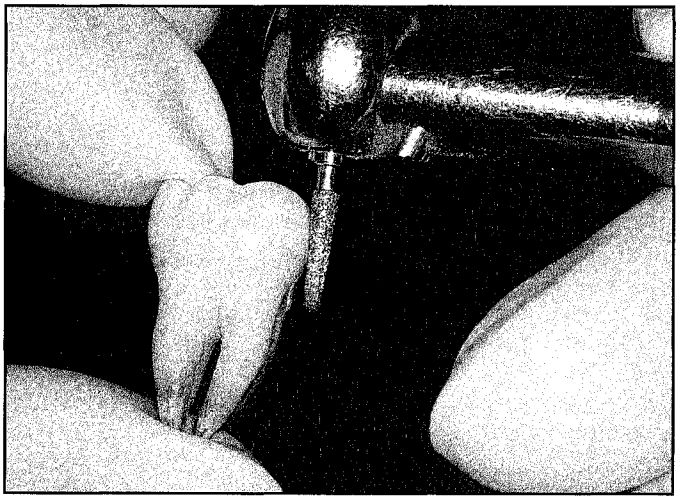

Figure 3. *Adjusting the mesial approximal contact of a natural tooth*

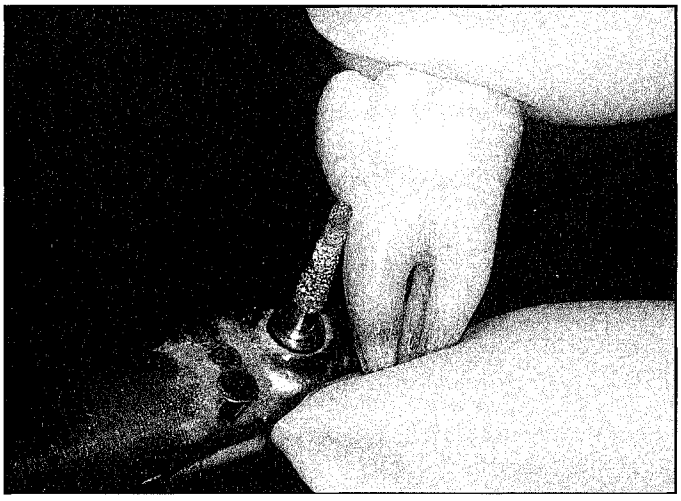

Figure 4. *Adjusting the distal root contour of a natural tooth*

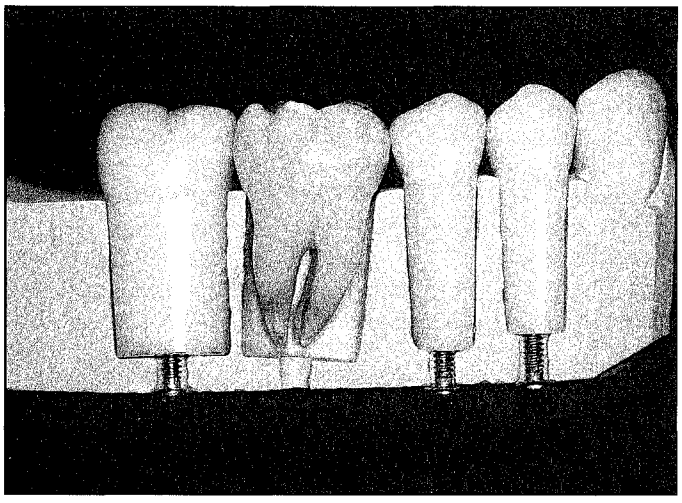

Figure 5. *Cutaway view of a dentoform model showing complete seating of a natural tooth*

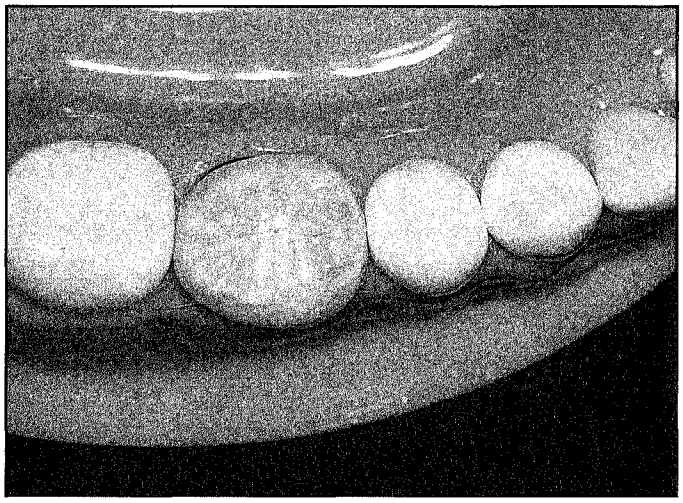

Figure 6. *Occlusal view of a natural tooth properly fitted to a commercial dentoform*

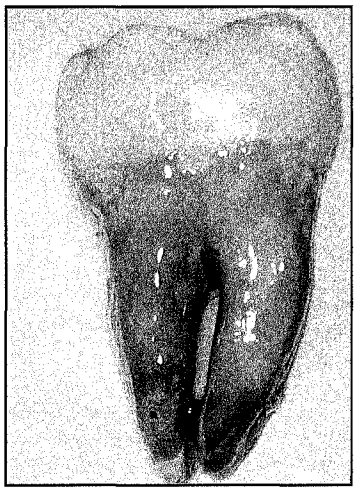

Figure 7. *Natural tooth retention is accomplished by coating the roots with polyvinyl siloxane impression material tray adhesive*

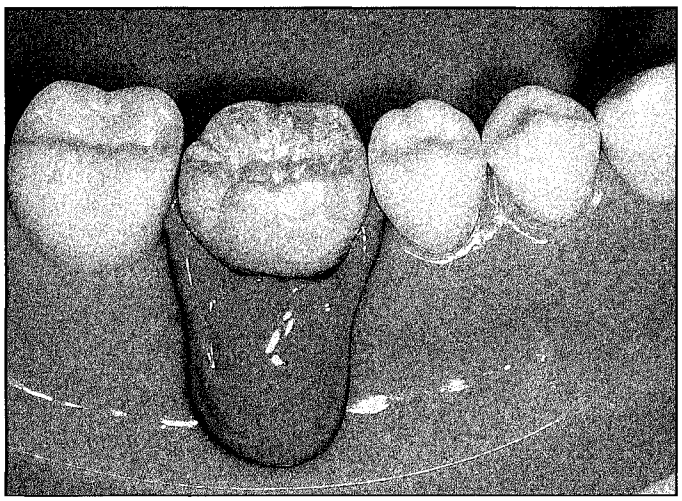

Figure 8. *Excess polyvinyl siloxane impression material that has extruded from the dentoform following insertion of a natural tooth into the previously filled socket*

test-fitted into the sockets. Disinfection of natural teeth includes scrubbing or ultrasonic cleansing with detergent followed by immersion in a 1:10 solution of sodium hypochlorite and water or other suitable liquid germicide (Centers for Disease Control and Prevention, 1993). Tooth roots may be contoured as necessary, including the removal of a single root of a multi-rooted posterior tooth, and approximal enamel surfaces may be adjusted to facilitate the insertion of the natural tooth (Figure 1-6). The steps that are involved with adjusting natural teeth that are slightly oversized are similar in principle to the steps that are followed to adapt a cast restoration to a tooth. Notching the tooth root is unnecessary for mechanical retention, because the roots are coated with polyvinyl siloxane impression material tray adhesive (Figure 7).

After fitting the tooth, polyvinyl siloxane impression material is injected into the dentoform socket, and the tooth is inserted (Figure 8). Light-bodied material for large roots and heavy-bodied material for small roots should produce comparable retention and mobility. Teeth may be positioned in an "extruded" orientation for the purposes of simulating exposure of root surface for practicing restorative techniques in this location. Upon setting, excess impression material is removed with a sharp blade. The occlusion may then be adjusted to facilitate proper closure of the dentoform. Polyvinyl siloxane impression material was selected over other elastomers because of the wide variety of viscosities that are available to simulate natural tooth movement. However, when using a natural tooth to anchor a rubber dam retainer, a polyvinyl siloxane with a very high viscosity such as a bite-registration material is recommended because of its rigidity and increased retentive properties. Removal of the natural teeth from the dentoform is usually accomplished by hand with only moderate force; however, the use of hemostats may be necessary when a higher-viscosity material is used. The elastomeric coating on the tooth root allows the tooth to be removed and repositioned into the dentoform as needed (Figure 9).

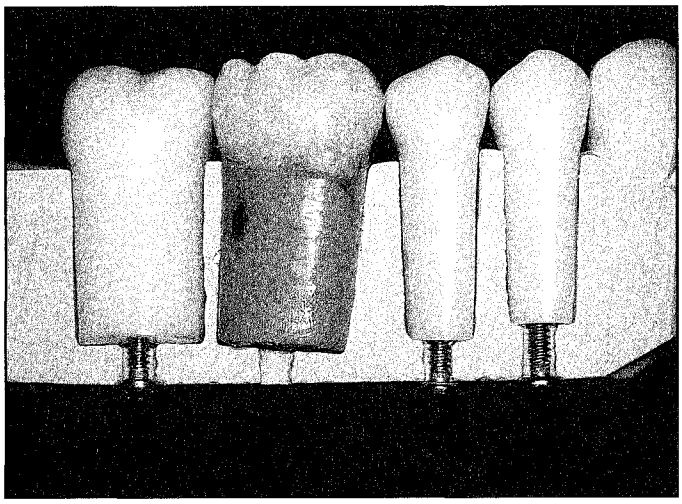

Figure 9. *Cutaway view of a dentoform model showing how the impression material covering the tooth roots conforms to the shape of the dentoform socket*

CONCLUSIONS

A simple technique has been presented for mounting natural teeth on a commercial dentoform. There are several practical advantages associated with this

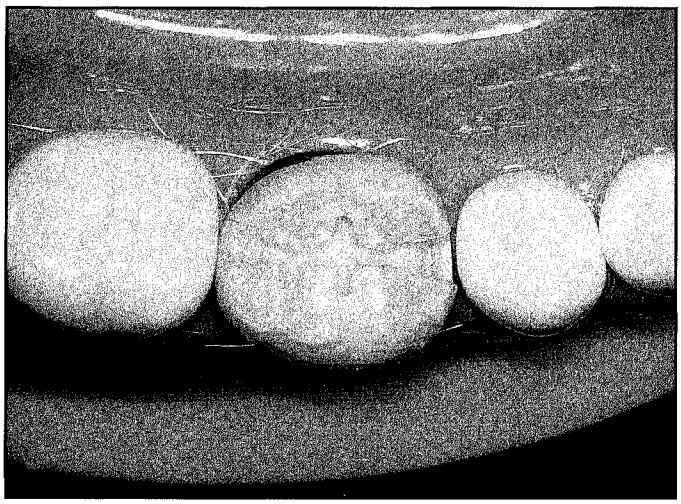

Figure 10. *Mesio-occlusal amalgam cavity preparation on a natural tooth in a commercial dentoform*

method of mounting teeth. As compared to using acrylic or plaster, silicone impression materials set faster, are cleaner to work with, and do not require any modification of the dentoform socket such as lubrication. In addition, the mounted teeth are slightly mobile, unlike the rigid condition that results from using the other materials. The ability to use natural teeth for caries removal, custom composite shade selection, and bonding with glass-ionomer materials in addition to the previously described benefits are several advantages of this technique (Figure 10).

(Received 31 March 1998)

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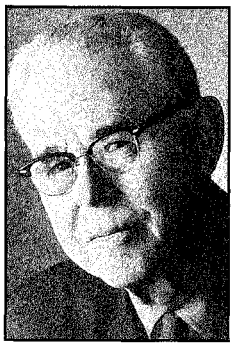
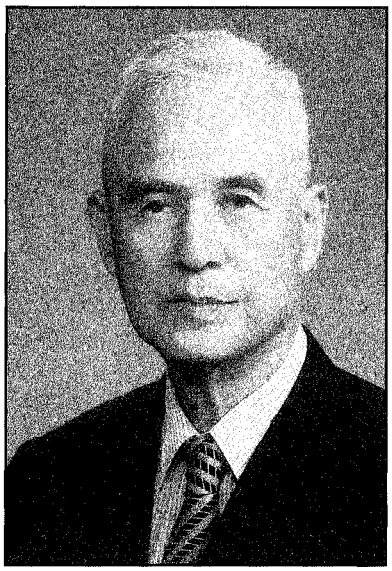
Hollenback Prize for 1999



George Hollenback



Takao Fusayama

It is a great honor for me to present Professor Takao Fusayama the 1999 Hollenback Memorial Prize. Dr Fusayama's significant contributions to dental research and to operative and restorative dentistry rank him as one of the true leaders of the profession.

Takao Fusayama graduated from the Tokyo Medical and Dental University in 1938. His teaching and research can best be described as ahead of its time. The honors he has received are too numerous to list, but they include the Wilmer Souder award; List of Honour, FDI; member of the Japan Academy (only dentist in this academy); Fulbright Scholar; and the ADA Gold Medal for Excellence in Dental Research. Now retired and a professor emeritus, he published 150 papers and 25 books during his distinguished 37-year career. His insight into the future directions of the profession were prophetic: dentin etching and bonding, minimal cavity preparation to preserve sound tooth structure, and caries-disclosing dyes are only a few of his visionary concepts.

Dr Fusayama's meritorious contributions have resulted in great benefits to the members of this academy and to their patients. We are most appreciative of his insights and enormous gifts to the dental profession. The Academy of Operative Dentistry is proud to present this award to Dr Takao Fusayama.

J W OSBORNE

DEPARTMENTS

ABSTRACTS

The editor wishes to thank the T-2 Comprehensive Dentistry residents at the Naval Dental School in Bethesda, MD, for their assistance in the preparation of these abstracts.

Shear bond strength of chemical and light-cured glass ionomer cements bonded to resin composites. *Farah CS, Orton VG & Collard SM (1998) *Australian Dental Journal* 43(2) 81-86.

(*University of Western Australia, Department of Pathology, Nedlands, Western Australia 6009)

A restoration involving the sandwich technique utilizes a glass ionomer, an adhesive resin, and a composite resin. The purpose of this study was to determine whether chemical bonding is enhanced by the use of resin-modified glass-ionomer cements (RMGICs) bonded to microfilled and hybrid composite resins over that of a conventional glass-ionomer cement and to study the effect of thermal stresses on the bond strength. One hundred and sixty samples of glass-ionomer cement mounted in phenolic rings were divided evenly into two groups; one of the groups was thermocycled 1079 times at 6-55 °C. Eight groups of 10 samples were tested, pairing Ketac-Bond and Photac-Fil with Visiobond bonding agent, and Vitremer with Scotchbond bonding agent. Photac-Fil was bonded to Pertac and Visiodispers composite resins, and Vitremer was bonded to Z-100 and Silux Plus composite resins. Ketac-Bond was tested with all four composite resins. The composites were bonded using clear plastic rings and were sheared with a crosshead speed of 5 mm/min and a 100 kg load cell. The mean and standard deviations were calculated (N=10) and compared for significant differences using ANOVA ($\alpha = 0.05$). Bond strength for nonthermocycled Ketac-Bond ranged from 0.04 - 0.21 MPa. The RMGICs showed significantly higher shear bond strengths: Photac-Fil/Visiobond/Pertac = 1.59 MPa, and Vitremer/Scotchbond/Silux Plus = 4.92 MPa. There was a significant difference in the mean bond strength (N=20) between Vitremer (4.48 MPa) and Photac-Fil (0.98) in the nonthermocycled group. Thermal stressing significantly reduces the bond strengths of RMGICs. Chemical bonding between self-cured glass-ionomer cement, Ketac-Bond, and composite resin is minimal. Chemical bonding does exist between RMGICs and composite resins. Since RMGICs do have a true adhesive bond to resin composites, they are therefore recommended for use in the sandwich technique.

Leakage associated with load fatigue-induced preliminary failure of full crowns placed over three different post and core systems. *Freeman MA, Nicholls JI, Kydd WL & Harrington GW (1998) *Journal of Endodontics* 24(1) 26-32.

(*University of Washington, School of Dentistry, Department of Endodontics, Seattle, WA 98195)

Paraposts, flexiposts, or cast posts were placed in 36 maxillary central incisors that were treated endodontically. Each post and core was prepared with a standardized ferrule height and full cast crown restoration and was subjected to cyclic loading until preliminary failure of the casting occurred as detected by a strain gauge. Fatigue loading was continued for 100,000 load cycles after preliminary failure. Each tooth was immersed in 0.5 % basic fuschin dye for 24 hours, sectioned, and evaluated for leakage. Experimental groups demonstrated more leakage than control groups. None of the post and core systems used surpassed the others in preventing or delaying the occurrence of preliminary failure. Although preliminary failure is not clinically detectable, leakage is possible a considerable distance down the prepared post space and consistently occurred at the cement tooth interface. Loss of a coronal seal will likely result in the eventual failure of the endodontic treatment.

Interfacial bond strengths of amalgam bonded to amalgam and resin composite bonded to amalgam. *Fruits TJ, Duncanson MG Jr & Coury TL (1998) *Quintessence International* 29(5) 327-334.

(*University of Oklahoma, College of Dentistry, Department of Operative Dentistry, Oklahoma City, OK 73190)

The purpose of this study was to determine the effects of bonding old amalgam to old amalgam, old amalgam to new amalgam, composite to old amalgam, composite to new amalgam; the effects of surface treatment versus no surface treatment; the

influence of using adhesive agents; and the difference these factors exert between amalgam and composite. One hundred sixty specimens were involved in testing amalgam, and 160 specimens were involved testing composite resins. Cylindrical amalgam specimens were fabricated in a split two-piece die measuring 4.75 mm in diameter and 19.00 mm in length. There were 32 group of 10 each. The 32 groups were divided into two groups of 16. The different factors tested were amalgam bonded to amalgam and resin bonded to amalgam. The factors evaluated were time: amalgam and composite resin samples bonded to amalgam after an initial set of 1 hour and after an initial set of 21 days. Various bonding methods were used: adhesive or no adhesive, and the use of air abrasion with aluminum oxide or not. All specimens were tested for transverse loading strength with a three-point flexure test to determine the maximum amount of load before fracture. Statistical analysis of the data was determined by the use of Duncan's New Multiple Range Test. The areas of fracture were observed with X60 magnification. The two techniques that produced the greatest bond strengths when amalgam was added to existing amalgam did not utilize a bonding agent. Composite bond strength was greatest when a bonding agent was used. Bonding composite to amalgam that had set less than an hour did not have acceptable bond strength.

Shrinkage stresses associated with incremental composite filling techniques. *Jedrychowski JR, Bleier RG & Caputo AA (1998) ***Journal of Dentistry for Children*** **65(2) 111-115.**

(*University of California, Los Angeles, School of Dentistry, Section of Pediatric Dentistry, Los Angeles, CA 90095)

The purpose of this study was to investigate the polymerization shrinkage stresses produced by composite resin placement in two-surface primary molar photoelastic models using different incremental filling techniques. Preparations were prepared on dentoform teeth simulating primary mandibular second molars utilizing 90° cavosurface angles and rounded internal angles. Cavity walls were cleansed with 27 μm alpha alumina particles and prepared with the primer and unfilled resin of Restolux SP-4, Restobond 3 dual dentin-enamel bonding agent. The various filling methods were oblique, gingivo-occlusal, faciolingual, modified-bulk filling, and bulk filling of the approximal box. All layers were polymerized with a visible curing light for 60 seconds. The teeth were photographed in the field of a circular polariscope. The photoelastic patterns are based on the number and closeness of lines (stress fringes) next to the restoration. The more stress fringes and the closer they are in the photoelastic model, the higher and more concentrated the stresses generated by the shrinkage. The oblique incremental filling technique and the gingivo-occlusal technique showed high stresses (maximum fringe order of 5), and they were dispersed gingivally; the faciolingual technique displayed a lower stress (4 fringes) with the higher stresses occurring at the pulpal and axial walls; the bulk filling and the modified-bulk technique stresses were lowest (maximum fringe order of 2-3) and the highest stresses were located under the composite-photoelastic interface. When utilizing incremental curing techniques, polymerization shrinkage stresses were not less than the stresses that occurred when using a bulk placement technique. On the contrary, the bulk and modified-bulk techniques produced the lowest stresses. The only time incremental placement is recommended is to ensure contact with the gingival floor in the approximal box and if the increments are greater than 4 mm. The author proposes that as few layers as possible be used.

Effects of topical fluoride treatment on tensile bond strength of pit and fissure sealants. Koh SH, Chan JT &You C (1998) ***General Dentistry*** **46(3) 278-280.**

(*University of Texas Dental Branch, Department of General Dentistry, Houston, TX 77030)

The purpose of this in vitro study was to determine whether topical fluoride application immediately prior to the placement of sealants has any significant effect on the retention of pit and fissure sealants. It has long been recommended that topical exposure to fluoride should be avoided before the placement of pit and fissure sealants to tooth surfaces, the rationale being that the products from fluoride treatment, mainly calcium fluoride, will reduce the bond strength and thus interfere with the retention of sealants. This precaution is printed on the product instruction pamphlet of some sealants. Forty noncarious permanent molar teeth were split mesiodistally to obtain 80 samples. They were placed in acrylic blocks, and the surface of each sample was ground flat to provide a uniform surface for the application of sealant. The enamel preparations were immersed in artificial saliva for 24 hours to allow the formation of a surface pellicle, and then allotted randomly to eight different groups of 10 samples each. All samples were cleaned with a prophylaxis paste containing fluoride, rinsed,

and air dried prior to the placement of topical fluorides. Sample groups were subjected to four different topical treatments, either (1) topical artificial saliva, (2) 1% NaF, (3) 1.64% SnF, or (4) 1.23% APF. All samples were rinsed and dried. Groups 1-4 were etched with 37% phosphoric acid gel, rinsed, and dried prior to the application of an unfilled pit and fissure sealant (Concise), which was than light cured for 20 seconds. Groups 5-8 were etched with 50% phosphoric acid liquid, rinsed, and dried prior to the application of a filled pit and fissure sealant (Caulk), which was then light cured for 20 seconds. Samples in all groups were stored for 24 hours prior to being debonded in tension on an Instron Universal Testing Machine. Bond strength was calculated in MPa. Data were analyzed by analysis of variance, and means were compared using a Tukey-Kramer interval calculated at the 0.95 significance level. NaF increased the bond strength of the unfilled sealant; SnF and APF had no significant effect. NaF and APF decreased the bond strength of the filled sealant, while SnF had no significant effect. The bond strength of the filled sealant was higher than or equal to that of the unfilled sealant. Clinically acceptable tensile bond strengths were maintained between all the fluoride-treated enamel surfaces and the unfilled or filled sealants. The topical application of either sodium fluoride, stannous fluoride, or acidulated phosphate fluoride had no significant clinical effect on the retention of pit and fissure sealants placed on fluoride-treated enamel surfaces.

Combining chemical agents and techniques to remove intrinsic stains from vital teeth. McEvoy SA (1998) *General Dentistry* 46(2) 168-172.

(University of Kentucky, College of Dentistry, Department of Oral Health Practice, Lexington, KY 40536)

The purpose of this article was to discuss the selection of appropriate chemical stain-removing agents to remove a variety of intrinsic stains from vital teeth. Hydrochloric acid is used to remove yellow-brown and white stains associated with fluorosis, disturbances in enamel mineralization, and localized effects from trauma or infection. Hydrochloric acid works by softening and dissolving the enamel to remove the stain and is recommended only for those stains that are developmental in origin and are in superficial enamel. This chemical is not recommended for TCN stains, which are primarily found in the dentin.

For in-office bleaching procedures use 30-35% hydrogen peroxide, and 10-15% concentration for home bleaching utilizing night guard splints. Hydrogen peroxide is given primarily to those with fluorosis, TCN stains, and stains caused from trauma. Hydrogen peroxide removes the same stains as hydrochloric acid except white discolorations. Concern arises with the home use of carbamide peroxide and potential abuse of the product by the patient. When there are multiple stains from different origins existing, a combination approach could be helpful. A combination of hydrogen peroxide to remove the yellow-brown stains and carbamide peroxide to remove all the white discoloration proves to be successful. Hydrochloric acid used first will remove most fluorosis stains, but remaining deep white or yellow-brown discolorations can be treated with a splint and 10% carbamide peroxide solution or by applying a 35% hydrogen peroxide solution right after the treatment with hydrochloric acid using a rubber dam. Another solution utilizing a combination approach would be: hydrochloric acid, then immediate application of the hydrogen peroxide while the rubber dam is still in place, then utilizing a splint containing 10% carbamide peroxide for home use.

Rather than masking stain with resin, veneers, or crowns, treatment of stain removal with a combination of chemical agents can be very conservative and beneficial.

Effect of dentin treatment with citric acid/ferric chloride solutions on glass ionomer bond strength. *Terata R, Nakashima K, Yoshinaka S & Kubota M (1998) *American Journal of Dentistry* 11(1) 33-35.

(*School of Dentistry, Iwate Medical University, Department of Operative Dentistry and Endodontics, 1-3-27, Chuou-douri, Morioka, Iwate, 020, Japan)

The purpose of this study was to investigate the effect of dentin treatment with mixed solutions of citric acid and ferric chloride on the tensile bond strength of resin-modified glass ionomers. One hundred twenty bovine mandibular incisors were ground to expose dentin. The teeth were divided into six groups of 10 teeth and treated as follows. Group 1 (control): the dentin was rinsed with distilled water for 15 seconds and dried with oil-free compressed air for 15 seconds; Group 2: the dentin was treated with Super Bond Dentin Activator (mixed solution of 10% citric acid and 3% ferric chloride) for 30 seconds; Group 3: the dentin was treated with Bondwell LC Conditioner (mixed solution of 12% citric acid and 1% ferric chloride) for 20 seconds; Group 4: the dentin

was treated with Scotchbond Multi-Purpose Etchant (10% maleic acid) for 15 seconds; Group 5: the dentin was treated with dentin conditioner (10% polyacrylic acid solution) for 20 seconds; Group 6: the dentin was treated with K-etchant (37% phosphoric acid solution) for 40 seconds. Specimens were stored in water at 37 °C. Vitremer and Fuji II LC were the resin-modified glass ionomers used. The tensile bond strength was measured with an Instron Testing Machine at a crosshead speed of 0.5 mm/min. The data were statistically analyzed by a one-way ANOVA and Dunnett's post hoc procedure for significant differences between control and each treated group ($P < 0.05$). Results showed that Super Bond Dentin Activator and Bondwell LC Conditioner increased the tensile bond strength of Vitremer and Fuji II LC. Scotchbond Multi-Purpose Etchant, Dentin Conditioner, and K-etchant are acid solutions that remove smear layers and have denatured dentin collagen. This denatured dentin probably prevented dentin treatment from increasing bond strength of the resin-modified glass ionomers. Super Bond Dentin Activator and Bondwell LC Conditioner contained citric acid and ferric chloride. The mixed solution of citric acid and ferric chloride removes the smear layer and does not denature the dentin collagen. These results supported the contention that dentin treatment with mixed solutions of citric acid and ferric chloride increased bond strength of resin-modified glass ionomers.

BOOK REVIEWS

ESTHETICS: DIRECT ADHESIVE RESTORATION ON FRACTURED ANTERIOR TEETH

Luiz Narciso Baratieri

Published by Quintessence Publishing Co, Inc, Chicago, 1998. 396 pages, 891 illustrations. $180.00.

This is a book that every dental clinician, every restorative and biomaterials researcher, and every dental student should read. The book deals with treatment of individuals presenting with fractured anterior teeth.

The content of this book is divided into 10 chapters, each with supporting references. The authors have been very careful in selecting superb photographs to document their presentations. Color photography is of unusually high quality throughout the book. The microphotographs (SEMs) are clean, clear, and enlarged so the reader can better understand the message of the text, and the drawings, tables, illustrations and graphs are professional in quality.

Chapter 1 deals with the fundamentals for the restoration of fractured anterior teeth. Here the author presents information on the etiology, prevalence, and incidence of fractures. He offers a classification of dental fractures and criteria in determining type of restoration. Many examples of before and after treatment are documented with excellent clinical photographs.

Chapter 2 discusses the principles of dental esthetics. Considerations of tooth size, shape, proportion, surface texture, position and alignment, color, embrasures, and balance are explained. Again, excellent photographs and drawings support and complement the text.

John Gwinnett presents a clear discussion on the mechanism of adhesion in Chapter 3. His excellent photomicrographs richly illustrate topographically a variety of demineralization patterns for which the mechanisms of bonding to tooth surfaces (enamel and dentin) can be achieved. He presents the case for and against total etch.

Chapter 4, written by Guy Willems, gives the reader extensive and current information on the nature of composite resins. This chapter will help the clinician select the most suitable composite resin for the restoration. The text is supported with excellent photomicrographs and information tables.

Light-curing units (photopolymerizers) are discussed with great detail in Chapter 5. Photoinitiated chemical reactions and problems related to inadequate polymerization are discussed. Techniques for maximizing polymerization are outlined.

Chapter 6 presents an extensive discussion on tooth fragment reattachment. Advantages, disadvantages, and classification of fractures that assist in the evaluation process and ultimately lead the clinician to success or failure in treating fractured anterior teeth are discussed in great detail. This chapter is supported with many excellent clinical photographs that help the reader in understanding the reattachment technique and prognosis.

Chapters 7 and 8 are entities unto themselves and give credence to the title of the book. Chapter 7 deals with direct adhesive restorations on fractured anterior teeth. The reader is guided in the sequential fundamentals of the operative technique. The authors have assembled excellent clinical photographs of very high quality, which greatly enhance the understanding of the reader. Chapter 8 is about direct composite resin veneers. Indications and counterindications for direct veneers with advantages and disadvantages are covered in great detail. Again,

excellent photography illuminates the techniques in the text.

Chapter 9 presents information on how forced eruption of teeth can be used to acquire and preserve biophysiologic balance in the area of the biologic width. The biological foundations involved in forced eruption are discussed. Many excellent clinical photographs enhance the reader's comprehension of the text.

Fractured anterior teeth with associated traumatic periodontal lesions are discussed in Chapter 10. Dentoalveolar trauma frequently offers dentists a difficult clinical protocol, and this chapter presents a biological basis for clinical procedures. The elements involved in the diagnosis of dentoalveolar trauma lesions are described.

This is an excellent book for those interested in esthetics. It tells how esthetics can be achieved with direct adhesives in the restoration of fractured anterior teeth.

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THE SCIENCE AND PRACTICE OF OCCLUSION

Edited by Charles McNeill

Published by Quintessence Publishing Co, Inc, Chicago, 1997. 550 pages, 650 illustrations (229 in color). $148.00.

The basic premise of this book is that "occlusion is a functional outcome of the interaction of the stomatognathic structures." The book is divided into two parts: Part I deals with the anatomical, biomechanical, physiological, and pathological principles of occlusion, which provides a biological basis for the practice of occlusion presented in Part II. Part I encompasses four sections, beginning with "Form and Function," followed by "Growth and Development," "Biomechanics," and "Tissue Response." After this foundation has been explored, Part II examines the clinical management of the occlusion. This includes "Treatment Goals," "Records and Diagnostic Tests," "Problem Solving through Treatment Planning," followed by two sections on various "Therapies" to complete the treatment. Most of the chapters included in this book were presented at the 1995 and 1996 Craniomandibular Institute's Annual Winter Seminars in Northern California. The 48 international contributors to this effort encompass a tremendous wealth of talent and experience in occlusion.

Part I. Biologic Principles and Interactive Jaw Mechanics: The "Form and Function" chapters are extremely well referenced and have excellent illustrations, many in color. The use of color in Chapter 5, "The Dynamics of Occlusal Relationships," is especially useful in illustrating cusp movement. Chapter 2, dealing with the temporomandibular joint, is particularly well illustrated and contains clear, concise explanations of common questions dealing with disk and condylar movement and control. Chapter 9, "Effect of the Physical Environment on Growth of the Temporomandibular Joint," provides an interesting chapter dealing with investigation of the role played by local mechanical events on chondroblastic activity. Overall, a very thorough coverage of Part I in clarity, content, illustrations, and references was provided.

Part II. Clinical Considerations for a Favorable Tissue Response: Chapter 22, "Clinical Decision-Making in Occlusion: A Paradigm Shift," was particularly interesting because it introduced the framework that is in use involving the patient, employers, insurance carriers, and government agencies as a consequence of soaring health costs. Chapter 23 "Fundamental Treatment Goals," delivers an excellent discussion of physiologic, nonphysiologic, and treatment of occlusion. Section 6 covers a broad range of topics from a basic history and examination to a discussion of cephalometric analysis and maxillofacial imaging. Section 7 begins with an excellent discussion of "Interocclusal Appliances: Do They Offer a Biologic Advantage?" This is followed by a discussion of the relationship between occlusion and periodontal disease, selective tooth grinding, and occlusal therapy considerations. Section 8 covers a wide range of areas, including the complex restorative case, complete dentures, maxillofacial prosthodontics, and implants. Section 9 rounds out the substance of this book by dealing with orthopedic repositioning, orthodontic therapy, and orthognathic surgery.

There is a tremendous amount and variety of current information set forth in this book, which makes it a very valuable reference source for many different specialty areas. Since the book was written assuming a certain basic knowledge of anatomy and occlusion, by far the majority of the information included in this excellent text would be of benefit to graduate students, specialists interested in occlusion, and faculty who are involved in teaching occlusion to their students.

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CLASSIFIEDS: FACULTY POSITIONS

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The University of Tennessee, Memphis, College of Dentistry seeks nominations and applications for the position of Chair in a newly restructured Department of Restorative Dentistry. The department includes the following divisions: operative dentistry, biomaterials, and prosthodontics. The College of Dentistry is one of six colleges comprising the University's Health Science Center. The College serves approximately 365 students in predoctoral and advanced training programs.

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Dr Russell O Gilpatrick
Associate Dean for Academic Affairs
University of Tennessee, Memphis
College of Dentistry
875 Union Avenue
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A full-time position, Division Director of Operative Dentistry, is available within the Department of Restorative Sciences starting 1 July 1999. Responsibilities include administration of the division, directing all clinical and preclinical educational activities relating to operative dentistry, and assisting faculty in developing a strong divisional research program. The successful candidate must have completed a postgraduate training program in operative dentistry with diplomate status being preferred. The candidate will be expected to have outstanding contemporary clinical skills, evidence of significant previous research and teaching experience, and be eligible for tenure at this institution. There is an opportunity for private practice or consulting one day per week. Salary will be commensurate with experience and credentials. Applications will be accepted until the position is filled. The University of Minnesota is an Equal Opportunity educator and employer. Curriculum vitae and letter of intent should be sent to:

Dr James R Holtan, Chair
Search Committee and
Department of Restorative Sciences
9-176 Moos Health Science Tower
515 Delaware St SE
Minneapolis, MN 55455

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ACADEMY OF OPERATIVE DENTISTRY, EUROPEAN SECTION SECOND ANNUAL MEETING

1-2 October 1999
Munich, Germany

RESTORATION OF POSTERIOR TEETH: THE EUROPEAN VIEW

This meeting will feature a panel of international speakers, who will discuss restorative treatment on posterior teeth. Poster presentations will be given on Saturday, 2 October. This meeting immediately follows the First Munich Esthetic Symposium. Additional information may be obtained by contacting:

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