OPERATIVE DENTISTRY

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Aim and Scope

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

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Guest Editorial

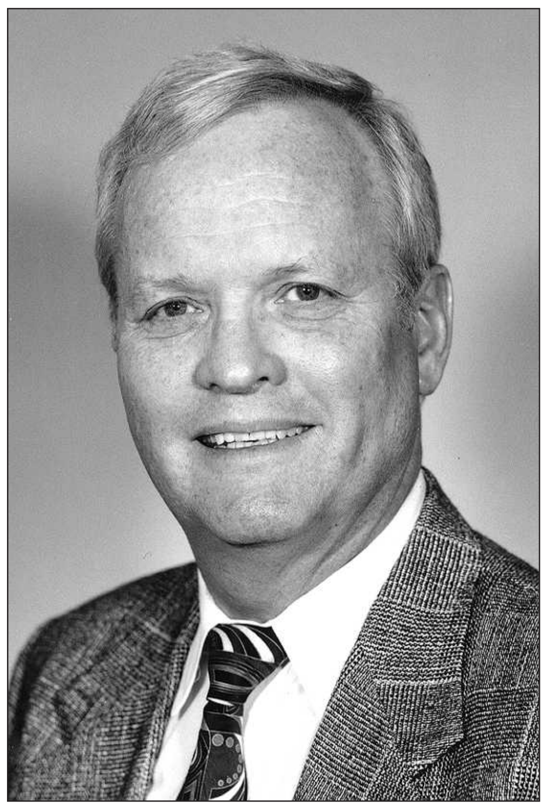
The Crossroads of Operative Dentistry: Being on the Right Track is Not Enough!!

When I was in dental school, there was not much difference in techniques or restorative materials incorporated into the Operative curriculum for dental schools across the country and Operative departments were considered the foundation of dental education. Therefore, it was not surprising when, in the 1970s, the Academy of Operative Dentistry was born, and with it, the superb journal *Operative Dentistry*.

That fledgling Academy has flourished and is now well over 1000 in membership. The *Journal*, supported by the loyal membership and total dedication of its Editor, Ian Hamilton and Managing Editor, Marty Anderson, began the difficult task of competing for readership with journals like the *Journal of Prosthetic Dentistry*. Slowly but surely, over time, our *Journal* has grown from its infancy into one of the top refereed journals in the world. With Dr Mike Cochran and the energetic team from Indiana taking the helm of our "flagship" *Journal*, new and wonderfully innovative progress is being made, further enhancing the reputation and importance of this publication.

But what part can our *Journal* play in Dentistry's future? Operative Dentistry's future is certainly at the crossroads. Throughout our country, the teaching of Operative techniques is becoming more and more diverse. For example, many schools believe in "conservation" of tooth structure and making partial coverage cast restorations part of their curriculum. Others feel that if a casting is necessary or a cusp is in need of coverage, full coverage is the only option.

To complicate matters further, there is a gigantic struggle between using amalgam for posterior restorations and tooth colored resin-composite materials.



Richard B McCoy

Ironically, what is driving this controversy is more media based than quality-of-treatment based, for the advertising of "white" and "esthetic results" has in many cases become more important than longevity and quality of treatment. The "extension-for-prevention" philosophy has been superceded by conservative preparations or "minimal intervention." With the voluminous, rapid changes of techniques and materials, Operative divisions/departments are having trouble keeping up. Decreases in the availability of qualified, viable faculty, as well as smaller Operative departments/divisions have made progressive change even more difficult.

I envision our *Journal* as the foundation for the future direction of our dentistry's educational objectives and techniques. The *Journal* is now up to 104 pages. I can envision having a section in every issue devoted to important clinical information for Operative educators, thereby enabling them to take the "right track from the crossroads."

Will Rogers once said, "It was not enough to be on the right track, for if you stop, you are still going to get run over when the train comes by!!" This is no less true for dentistry. We need to keep moving and improving. This is the important role for our *Journal*!! I am excited and appreciate the direction our *Journal* is headed and know that Dr Cochran and his crew will keep us moving down the correct track in the future.

Past editors of our prestigious *Journal* and readers who have remained loyal to our publication should look upon the future of our discipline and excellence of our *Journal* with pride!!

Richard B McCoy
University of Washington
School of Dentistry

Commentary

Dr Richard B McCoy assumed the editorship of *Operative Dentistry* in 1995, when Dr Max Anderson left the University of Washington to pursue yet another aspect of his professional career. Dick had served as Associate Editor during Dr Anderson's tenure and was uniquely qualified and in perfect position to lead the *Journal.*

As with everything he does, Dr McCoy approached his new role as Editor with dedication, determination and imagination. He knew the talent of his editorial team and encouraged and supported them to expand their productivity. He guided the publication from 1995 through 1999 and produced 30 outstanding issues for the readership. He strengthened our Editorial Board and set a policy that utilized three reviewers for each submitted manuscript. He gradually expanded the *Journal* from 40 to 64 pages and published his final issue at 72 pages with a new "spine" binding that displays the *Journal's* name and volume for easier shelf reference. His efforts resulted in international recognition of *Operative Dentistry* as the most highly regarded publication in its field as well as a number of citations for accuracy of references and overall quality. All of this has assured a continuing influx of excellent manuscripts from around the world that provide our readers with valuable information for their daily delivery of health care.

I am personally grateful to Dr McCoy for helping prepare me to edit the *Journal*. When Dick became Editor, he asked me to become his Associate Editor and, despite the physical distance between our offices, made me feel as though I was an integral part of his team. While moving the *Journal* from Washington to Indiana, Dick and his entire group gave us the necessary assistance, information and encouragement to make us believe we could actually accomplish the transition with our sanity intact. My only complaint is that Dick assured me that this was an easy job that only involved about a half-day per week's effort… he still laughs at me every time we see each other and keeps offering me swamp land for sale. Fortunately, he is so grateful that I took over his job that he has stayed on as one of my associate editors. Dick McCoy is an outstanding editor, mentor and friend. He continues to provide valuable support and leadership to this *Journal* on a daily basis.

I would like to offer my heartfelt appreciation to the *Journal's* previous editors, Drs Hamilton, Bales, Anderson and McCoy, for producing a journal of outstanding quality, importance and service to the discipline of Operative Dentistry. Thank you one and all for your unselfish commitment to the Academies and readership.

Michael A Cochran
Editor

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Buonocore Memorial Lecture

Adhesive Dentistry in the 21ST Century

Jean-François Roulet

Michael Buonocore

Jean-François Roulet

INTRODUCTION: A LOOK BACK

Looking back means informing yourself and honoring the pioneers. This seems to be an easy task, especially today when great data banks and search machines are available. Based on a literature search, one can acquire the knowledge to learn who the pioneers were, that is, who was the first to describe a principle, procedure or invention. Upon first look, there seems to be no problem; however, quite often it is difficult to determine who the pioneers *really* were. Let us take, for example, nuclear physics (Mortimer, 1996; Encarta, 1998).

Approximately 30 years after Dimitrij Mendelejew discovered the periodic system in 1869, the basic key to the understanding of the chemistry of atoms, scientists began to reveal their ultrastructure.

In 1896, AH Bequerel discovered that Uranium emitted an intensive radiation. Pierre and Marie Curie conducted some fundamental work on radiation and discovered the elements Radium and Polonium.

Ernest Rutherford and his coworkers demonstrated that atoms were not solid spheres. By bombarding thin gold foils with α-particles, they observed that most particles just went through the foil with only a few being reflected or deflected. They concluded that atoms consist of a nucleus and a shell.

Niels Bohr substantially refined this model by defining the energy of the electrons circulating the nucleus.

In 1933, Fréderic and Irène Joliot-Curie discovered that stable elements could become unstable and radioactive if bombarded with particles. Doing this, the structure of the nucleus is changed; the result is a radioactive isotope.

John D Cockcroft and Ernest TS Walton bombarded Lithium with protons of high velocity, creating two Helium atoms based on one Lithium. Based on their 1932 experiments, they calculated that the energy within the nucleus is extremely high. And finally, Otto Hahn, Lise Meitner and Fritz W Straßmann announced in 1939 that they had successfully split Uranium by hitting it with neutrons.

So far it is easy to correlate the event with the person. But when the first atomic bomb was exploded in the Alamogordo Desert in New Mexico around dawn on July 16, 1945, scientific facts were brought together in a dramatic way. Proof was given that the scientists were right. It is difficult and complex to identify the pioneers of this event, which has fundamentally changed the world. Who should be quoted in a retrospective report as scientifically responsible?

- Albert Einstein, whose relativity theory was formulated while working for the Swiss patent office in Bern (1905), was the scientific backbone of nuclear physics.

Universitätsklinikum Charité, Medizinische Fakultät der Humboldt-Universität zu Berlin, Campus Virchow-Klinikum, Zentrum für Zahnmedizin, Abteilung für Zahnerhaltung und Präventivzahnmedizin, Augustenburger Platz 1, D-13353 Berlin

Jean-François Roulet

• Otto Hahn and Friedrich Straßmann, the first to demonstrate that atoms may be split based on experiments conducted in Berlin (1939).

• Leo Scillard, who, while in New York in February 1939, borrowed $2000 from a friend, rented one gram of Radium (used at the time for medical irradiation), bought 500 pounds of Uranium and bombarded it with the neutrons produced by the radium? His simple experiment confirmed his calculations. The uranium nuclei bombarded with neutrons produced more neutrons than were used for the bombardment that demonstrated that a chain reaction, which is the prerequisite for the instantaneous energy release in a bomb, is possible.

• Enrico Fermi, the scientific leader of the team that started the first controlled chain reaction in a nuclear reactor at the University of Chicago in December 1942.

• Robert J Oppenheimer, the scientific director of the Los Alamos laboratories, where the bomb was finally built (Spiegel 1957, Jungk 1996).

This little excursion into a different scientific world clearly shows the problem of correct quoting. Let us go back into our scientific world where these things are also not easy. If we look at adhesion, it is not as spectacular as in nuclear physics but quoting is not simpler. Who are the pioneers?

• P Castan (1938), a chemist employed by the DeTrey Company in Zürich (Switzerland) who synthesized the epoxi resin? Epoxy resins are powerful adhesives but were not used in dentistry with the exception of applying it as a root canal sealer (AH-26) (Schroeder, 1954). The company sold the patent to Ciba-Geigy, which has established epoxy resins as a standard for many industrial applications (boat hulls, skis, radar domes, etc). Furthermore, the epoxy resin is one part of the bis-GMA resin that Bowen (1962) had patented as part of the first composite resin. Without composites, adhesive and aesthetic dentistry would not be possible.

• O Haggar (1951), another Swiss chemist at the DeTrey company who developed a dental adhesive based on glycerophosphoric acid dimethacrylate, the first commercially available dental adhesive (Sevriton Cavity Seal, DeTrey , CH 8000 Zurich, Switzerland)? The product was not successful because the PMMA-based restorative material (Sevriton, DeTrey, CH 8000 Zurich, Switzerland) used with it had too much polymerization shrinkage.

• IRH Kramer and JW McLean (1952), who described an "intermediate layer by glycerophosphoric acid dimethacrylate" in dentin? With today's knowledge, this could be interpreted as a hybrid layer formed by a self-etching dentin adhesive.

• MG Buonocore (1955), who first described the enamel etching technique with phosphoric acid, which for many years was the base for any adhesive procedure?

• N Nakabayashi, K Kojima and E Masuhara (1982), who were the first to describe a technique that produced a hybrid layer by etching dentin and penetrating it with hydrophilic monomers?

• T Fusayama (1987), who described the concept of total etching and total bonding as a successful way of filling cavities?

• J Kanca (1991), who successfully promoted the total etching-total bonding concept in the US against the opposition of most dental schools that were claiming etching dentin is harmful for the pulp?

• AD Wilson and BE Kent (1971), inventors of the glass-ionomer cement, which is the first self-adhesive dental restorative material?

This lecture honors Michael G Buonocore. Therefore, we must go back to the early 1950s. During that time operative dentistry was characterized as unsuccessfully fighting caries by removing the symptoms by placing restorations. These restorations were made according to Black's principles and followed purely mechanical thoughts with gold foil, amalgam and silicate cement. With these facts in mind, one must conclude that for that time bonding was visionary.

TODAY: THE BENEFITS OF ADHESION

General Concepts

Today's dental world is completely different. It is characterized by a worldwide caries decline in industrialized countries (Glass, 1982; Löe, 1987; Marthaler, 1990). Furthermore, we have stable and durable aesthetic restorative materials and reliable bonding systems that enable us to bond to enamel, dentin, ceramics and composites.

There has also been a revolution in cavity preparation. The old and traditional methods of cavity preparation were material driven and thus, tooth destructive. Based on the physical and mechanical characteristics, eg, amalgam, the dentist was forced to cut large cavities just to insert the material.

Based on the possibilities of adhering the restorations to tooth structure, a new cavity preparation philosophy has emerged: cavity size and shape is strictly defect-oriented and minimally invasive. The maximum amount of healthy tissue is preserved and the cavity extension is limited to technical parameters: giving sufficient access to remove diseased tissue and allow for inspection of the cavity (Figure 1).

Such small cavities can no longer be drilled with rotary-type instruments, eg, tungsten carbide steel or diamond burs, which are very effective but also destructive.

Figure 1. *Minimal invasive cavity preparation. The removal of sound tooth structure is reduced to the maximum.*

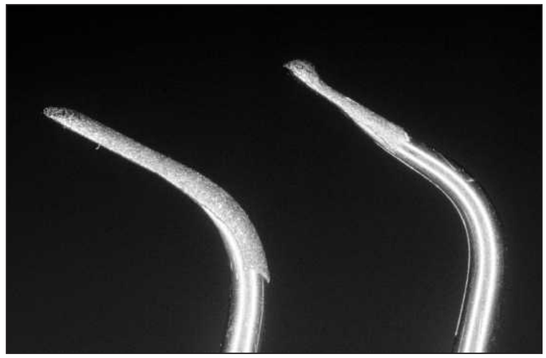

Figure 2. *One-side coated diamond instruments for use in oscillating handpieces (Sonic Sys, KaVO, D-88400 Biberach, Germany).*

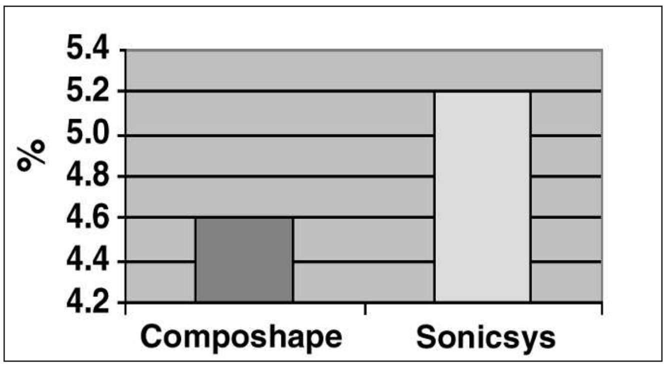

Figure 3a. *Percent of marginal opening of the occlusal portion of Class II composite restorations prepared with two different techniques (from Schünemann, 1997).*

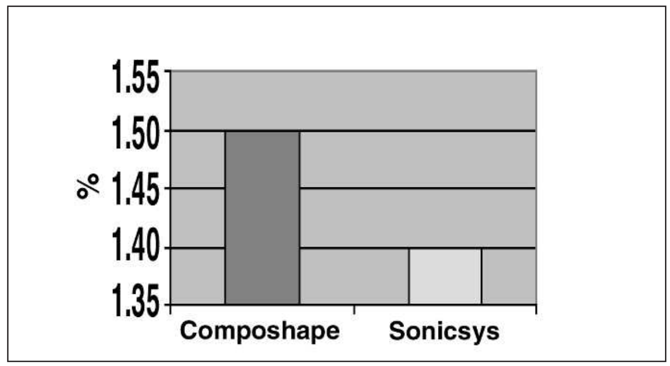

Figure 3b. *Percent of marginal opening of the vertical portion of Class II composite restorations prepared with two different techniques (from Schünemann, 1997).*

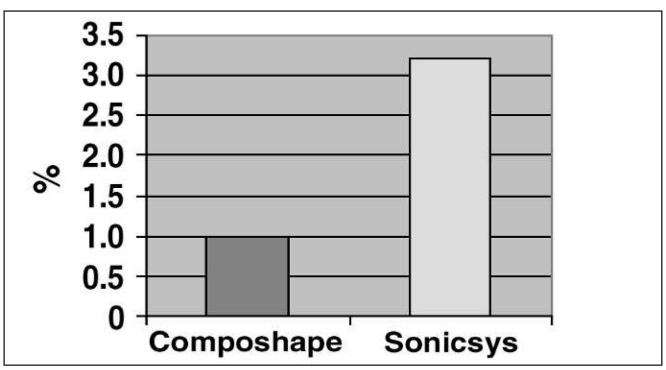

Figure 3c. *Percent of marginal opening of the cervical portion of Class II composite restorations prepared with two different techniques (from Schünemann, 1997).*

New oscillating instruments (Figure 2) enable the dentist to cut very small cavities, only as large as necessary, to remove decayed tissue and allow for optical control of the cavity. Furthermore, these tools allow far better damage control to neighboring teeth (Hugo, 1996). However, students trained in this way have problems cutting precise, well-defined cavities because they were never taught to imagine and realize predetermined cavity forms.

In a study presented by Schünemann (1997), it was shown that it is possible to produce high quality restorations with cavities cut with oscillating instruments. Cavities were cut and finished with rotating diamond burs and finishing diamonds (Composhape, Intensiv, CH-6906 Lugano, Switzerland) or with oscillating diamond files (Sonic-Sys, KaVo, D-88400 Bieberach, Germany). Filled with composite resins, the teeth were subjected to thermocycling and the margin quality was analyzed in the SEM. The results showed clearly that the oscillating instruments had no negative effects on the margin quality of the composite restorations (Figure 3).

The above-mentioned changes in philosophy have severely changed the way operative dentistry is performed:

- Macro retention with undercuts are now obsolete.
- Using retentive pins and screws has completely faded out.
- We now rely completely on micromechanical retention provided by adhesive techniques.

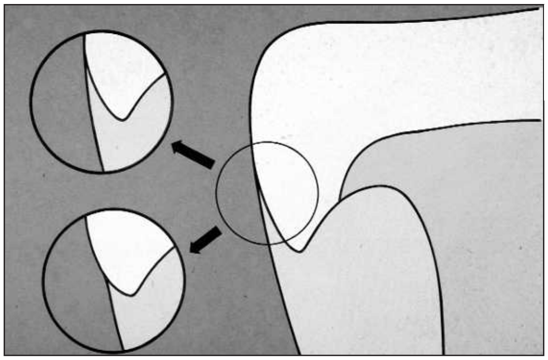

Figure 4. *The most important principle for placing unperceptible restorations: by placing a bevel with no defined finishing line, the transition between composite material and tooth remains undefined. This tricks the eye, which cannot perceive the borderline between composite and tooth.*

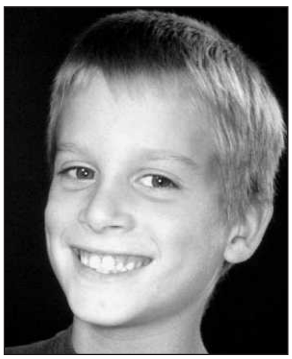

Figure 5a. *The second principle to follow for invisible restorations: replace enamel with transparent composite and dentin with a more opaque composite. Patient MR (eight years old). The incisal edges of both central incisors are repaired with composite after trauma.*

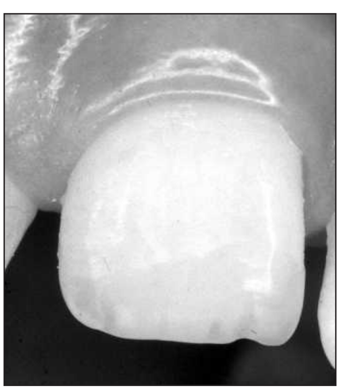

Figure 5b. *Tooth 11: almost the whole incisal edge is reconstructed in composite.*

As a consequence, fractured incisors can be restored by just bonding the fragments back to the tooth, even if the pulp was severed by the traumatic incident (Farik, Munksgaard & Andreasen, 2000).

Adhesive Techniques for the Restoration of Anterior Teeth

Due to adhesive techniques, it is possible to insert virtually invisible restorations in teeth, provided the following rules are respected:

- Placing long bevels to allow a continuous, unperceptible transition from the tooth to the restoration. Since composites are quite translucent, they will pick up in thin layers the color of the tooth (Figure 4).

- If a dentist understands the opacity/translucency concept of the way a tooth is made by nature, he/she can create natural looking restorations. Modern composite materials are color stable and can be polished to a high gloss, enabling the dentist to create absolutely unperceptible restorations (Figure 5).

Figure 5c. *The same patient 7.5 years later after a new trauma, which has created an intrusion and pulp necrosis. Status before root canal treatment, six weeks after trauma. The tooth has considerably darkened. Note that the restoration has followed this darkening because the bulk of the restoration was made out of a transparent "enamel substitute" composite.*

Figure 5d. *The same tooth after root canal treatment and bleaching procedure (thermocatalystic). The whole tooth is now brighter. Note that the restoration followed the color change (see explanation in Figure 5c).*

- Due to reliable adhesion, it is also possible to bond ceramic veneers to anterior teeth (Figure 6). Ceramics that contain a glass phase (feldspathic ceramics, glass ceramics) may be etched with hydrofluoric acid. The result is a selective dissolution of the glass phase, denuding the crystals of the ceramic, thus creating a micro-mechanical retention. Since ceramic surfaces are hydrophilic, one must hydrophobize the ceramic surface by silanization in order to increase the wettability of the ceramic for hydrophobic resins (acrylates) (Calamia, 1983).

- Ceramic veneers are a well-established, well-documented clinical procedure with an excellent longevity record of up to 15 years (Fuzzi, 2000). With a careful treatment plan and a well-controlled approach, it is possible to fulfill the highest aesthetic expectations of our patients (Magne & Douglas, 1999).

Figure 6. *Ceramic veneers inserted in the maxillary front teeth and premolars to hide the effect of amelogenesis imperfecta.*

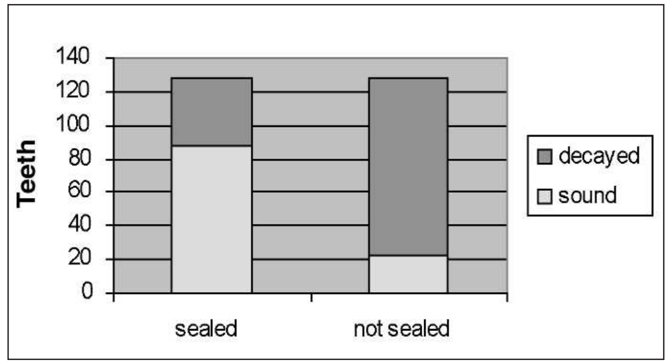

Figure 7. *The caries preventive effect of fissure sealing after 15 years (from Simonsen, 1991).*

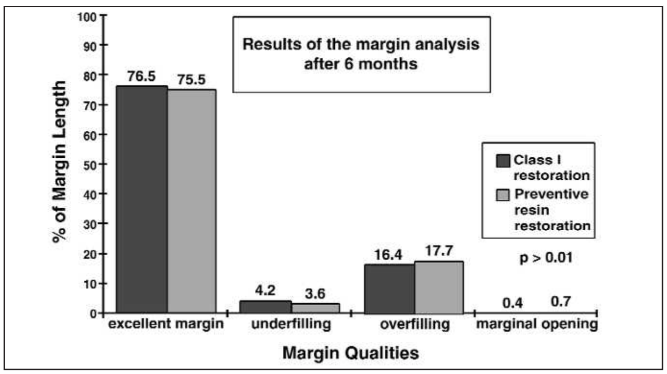

Figure 8. *Quantitative margin analysis (SEM 200x) of Class I restorations and preventive resin restorations after six months in vivo. Note the absence of marginal openings (from Noack & others, 1991).*

Adhesive Techniques for the Restoration of Posterior Teeth

Cueto and Buonocore (1967) first described the preventive potential of adhesive techniques. By etching the occlusal surface of posterior teeth and subsequent sealing of the fissure system with acrylates, it is possible to effectively prevent the colonization of the fissure by bacteria and thus prevent the occurrence of fissure caries. This method is a very effective and economic way to prevent fissure caries in children and adolescents (Figure 7) (Simonsen, 1991).

A natural extension of this technique is the preventive resin restoration proposed by Simonsen (1978). With this minimal invasive restoration technique, small caries is locally excavated, then the dentin is sealed together with the fissure, and the defect is filled with composite. Such restorations completely seal the fissure system (Noack, Bergmann & Roulet, 1991).

The use of a diagonal layering technique (Noack & others, 1991) demonstrated in a clinical study that it is also possible to obtain restorations with virtually no marginal openings with Class I composite restorations (Figure 8).

After a long phase of improvement, composites have established themselves as an adequate treatment for small and medium-sized cavities in posterior teeth. The good longevity data reported in the literature (Table 1) are only possible due to efficient adhesive techniques.

For large cavities and multiple restorations, tooth-colored inlays are the method of choice (Dietschi & Spreafico, 1997; Roulet and Spreafico, 2000). Today a dentist has many options to make a tooth-colored inlay.

The direct inlay technique is indicated to restore up to two teeth at a time with one or two-faced cavities with a simple design.

The inlay is performed by placing few composite increments into a tapered cavity previously insulated with two coats of an insulating glycerin gel medium (Separator, Coltène, CH-9450 Altstätten, Switzerland). A base with a conventional glass-ionomer cement is placed in order to fill eventual undercuts.

After the in-mouth light polymerization, the inlay is removed, the interproximal anatomy, if necessary, is corrected and refined. Lastly, after the heat and light treatment is conducted in a special oven (DI 500, Coltène, CH-9450 Altstätten, Switzerland), the restoration can be luted with composite resin cement. The direct composite inlay is perhaps the most economic way of producing luted restorations, and undoubtedly achieves inlays of optimal accuracy (Peutzfeldt & Asmussen, 1990).

A better way to perform composite inlays is the chairside technique. This method is best indicated to restore large intracoronal cavities (Class I and II).

This technique lies in making the composite restoration on a silicon model obtained from a cavity impression. The cavity impression can be made with alginate material, but a more accurate impression using silicon is preferable. A specially-formulated fast-setting vinyl polysiloxane dye material (Mach-2 Die Silicone, Parkell, Farmingdale, USA) is injected into the

Table 1: *Longevity of Posterior Composite Restorations*

Year of Publication	Authors (First)	Duration of Observation (Years)	Class	Material	Number of Restorations	Survival Rate (%)	Annual Failure Rate (%)
1988	Wilson	5	I and II	Occlusin	67	86	2.8
1989	Moffa	5	III	Composite	365	80 55	4 9
1991	Barnes	5B	III	Ful-Fil	33	90 77	2 2.9
1993	Mjör	5	II	P-10	91	85	3
1994	El Mowafy	5	I and II	Composite	191	89.5	2.1
1995	Pallesen	10	II	Miradapt, P-10, P-30	93	84	1.6
1998	Helbig	5	I and II	P-50	27	88.9	2.2
1998	Mair	10	II	P-30, Occlusin, Clearfil Post	56	92.2	0.7
1988	Nordbo	10	II	Occlusin/ Ful-Fil	34/17	88/59	1.7/5.9
1998	Skeeters	15	I and II	Estilux Posterior	19	95	0.3
1998	Wassell	5	II	Brilliant	65	95	1
1999	Raskin	10	I and II	Occlusin	100	50-60	4-5
1999	Wilder	17	I and II Nuva-Fil	Estilux, Uvio-Fil	85	76	1.4

impression after the impression is insulated with an insulating spray (New Break Agent, ADM SRL, Muggiò, Italy) and a working model is obtained in a few minutes. Dyes can be separated with a scalpel in order to obtain an optimal adaptation and contour of the restoration in the cervical region, as well as to achieve an efficient interproximal contact.

The restoration is completed with few increments of composite and luted in the same appointment. In the case of intracoronal restorations, the occlusal anatomy can be easily and better reached when compared to the direct technique. However, with this technique, the antagonist reference is not available, and complex restorations are built-up only with the reference of the neighboring teeth, leading sometimes to unavoidable retouches after the cementation.

Serial Class II cavities, partial or full coverages, cannot be properly restored using the two aforementioned techniques. Therefore, indirect composite methods are best indicated for such cases, although they need at least two clinical sessions with temporization and laboratory fabrication of the restorations. The indirect technique's main advantage is to provide restorations with optimal occlusal anatomy because the restoration is performed with the reference of the antagonist arch.

Indirect composite inlays and onlays can be fabricated with conventional light-cured small particle hybrid materials normally used for the direct restorations.

Some new materials specifically developed for crown and bridge work are also indicated for the indirect restorations (eg, Belle-Glass, Kerr, Orange, CA 92867, USA; Sculpture FibreKor, Jeneric/Pentron, Wallingford, CT 06492, USA; Targis-Vectris, Ivoclar, FL-9494 Schaan, Liechtenstein). These systems require special and expensive devices for cure and post-cure; manufacturers declare optimal mechanical and physical properties and excellent surface stability. Different clinicians have demonstrated that excellent aesthetic results can be achieved with such materials (Culp & Liebenberg, 1998; Fahl, 1998; Miara, 1998; Rifkin, 1998); however, to date, no scientific data are available regarding their clinical behavior and longevity.

With the exception of CAD/CAM-produced inlays (Cerec, Sirona, D-64625 Bensheim, Germany), ceramic inlays are produced with indirect techniques. As for composite inlays, one has to consider the brittleness of the material and prepare cavities with rounded internal angles and a butt joint configuration of the cavosurface angle. It is safe to respect a minimal ceramic thickness of 1.5 mm. Since it is difficult to perform corrections on the inlays during the try-in session, the dentist should focus on a perfect impression technique.

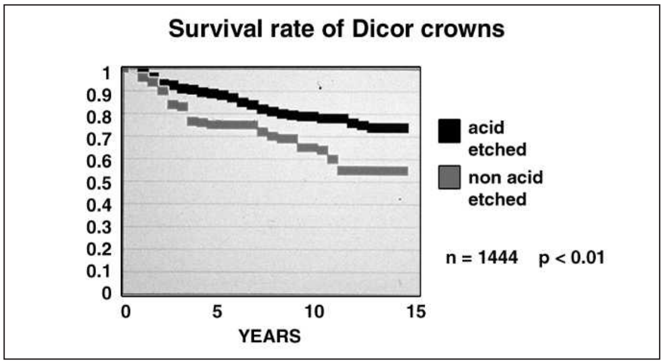

Figure 9. *The longevity of glass ceramic restorations (Dicor). Bonded restorations are compared with cemented restorations (from Malament and Socransky, 1999).*

Figure 10. *Glass ceramic inlays (Dicor). Note the precise fit.*

A good bond between the ceramic and the tooth is the prerequisite for success. The longevity of bonded ceramic restorations is approximately twice that of a cemented one (Figure 9) (Malament & Socransky, 1999). Therefore, performing the surface treatment of the inner surface (etching with hydrofluoric acid and silanization) immediately prior to insertion in the dental office is highly recommended. The ultrasonic insertion technique (Roulet & others, 1992; Eidenbenz & others, 1992, 1993; Noack & others, 1991) is well documented and has shown good clinical results regarding the margin quality (Noack, Locke & Roulet, 1993).

Sintering low-fusing ceramics directly on dyes made of investment material may produce inlays. Glass ceramics (cast or pressed) are also an easy way to produce well-fitting inlays because the lost wax technique may be used (Figure 10). Furthermore, there is the technique of milling ceramic inlays out of industrially produced blocks. There are basically two techniques available: copymilling (Celay, Mikrona, CH-8957

Table 2: *Longevity of Ceramic Inlays*

Year of Publication	Authors (First)	Duration of Observation (Years)	Class	Material	Number of Restorations	Survival Failure Rate %	Annual Failure Rate %	Remarks
1992	Mörmann	5	II	Cerec	8	100	0	2 inlays fractured
1994	Walther	5	I and II	Cerec	1011	95	1	
1995	Otto	5	II	Cerec	100	98	0.4	
1996	Kanzler	6,5	II	Ceramco	280	85	2,3	
1997	Berg	5	II	Cerec	51	94.1	1.2	
1997	Roulet	6	I and II	Dicor	123	76	4	
1998	Felden	7	inl/o	Dicor, Empress, Cerec, Ducera	287	94.2	0.8	
1998	Fuzzi	10	I and II	Microbond Nat. Cer, Fortune	183	97	0.3	
1998	Hayashi	6	I and II	G-Cera Cosmotech II	49	92	1.3	
1998	Lehner	6	inl/onl	Empress	138/17	94.9	0.9	
1998	Reiss	7.5	I and II	Cerec	1011	91.6	1.1	
1998	Sjögren	5	II	Cerec	66	89	2.2	
1998	van Dijken	6	II	Mirage (resin cement) Mirage (GIC)	58 57	88 74	2 4.3	
2000	Reiss	10 12	I II	Cerec	1010	90 84.9	1 1.3	

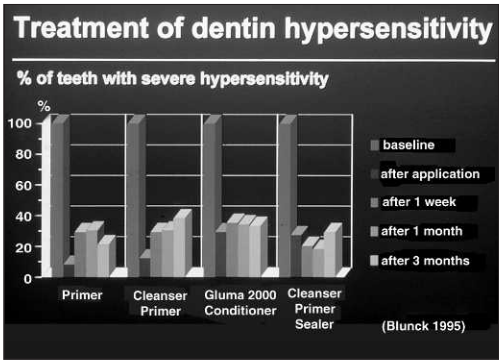

Figure 11. *Hypersensitivity of teeth before and after sealing the cervical dentin with dentin adhesives (from Blunck and Roulet, 1996).*

Spreitenbach, Switzerland) and CAD/CAM techniques (Cerec, Sirona, D-64625 Bensheim, Germany) (Roulet & Herder, 1991).

Contrary to composite inlays, the longevity of ceramic inlays is very well documented with observation times up to 10 years (Table 2).

Extended Use of Adhesive Techniques

Adhesive techniques have also helped to control a rather uncomfortable problem—teeth hypersensitivity. In most cases, this problem results from abrasion and/or erosion of the dentinal tubules exposed to the oral cavity in the buccal-cervical area of the tooth, permitting micro liquid movements in the odontoblastic process. By sealing this dentin with adhesives, the pain sensation can be relieved for up to three months (Blunck & Roulet, 1996) (Figure 11).

The adhesive technique has not only profoundly changed operative dentistry, it has also heavily influenced orthodontics. Bonding brackets, in most cases, not only omits placing bands as a base for brackets which are not ideal from a periodontal perspective, it also makes it possible to use porcelain brackets that provide a great aesthetic advantage (Proffit & Fields, 2000).

Prosthodontics has also benefited from adhesive techniques. It started many years ago with the bonded bridges (Rochette, 1973) which have become more sophisticated over the last 15 years (Degrange & Bouter, 1997; Thompson, Wood and DeRijk, 1997). Based on good experience with these retainers, prosthodontists even started to use bonded retainers for removable partial dentures (Marinello & Meyenberg, 1997). Furthermore, more fixed prostheses are bonded today than cemented (Degrange, Cheylan & Samama, 2000).

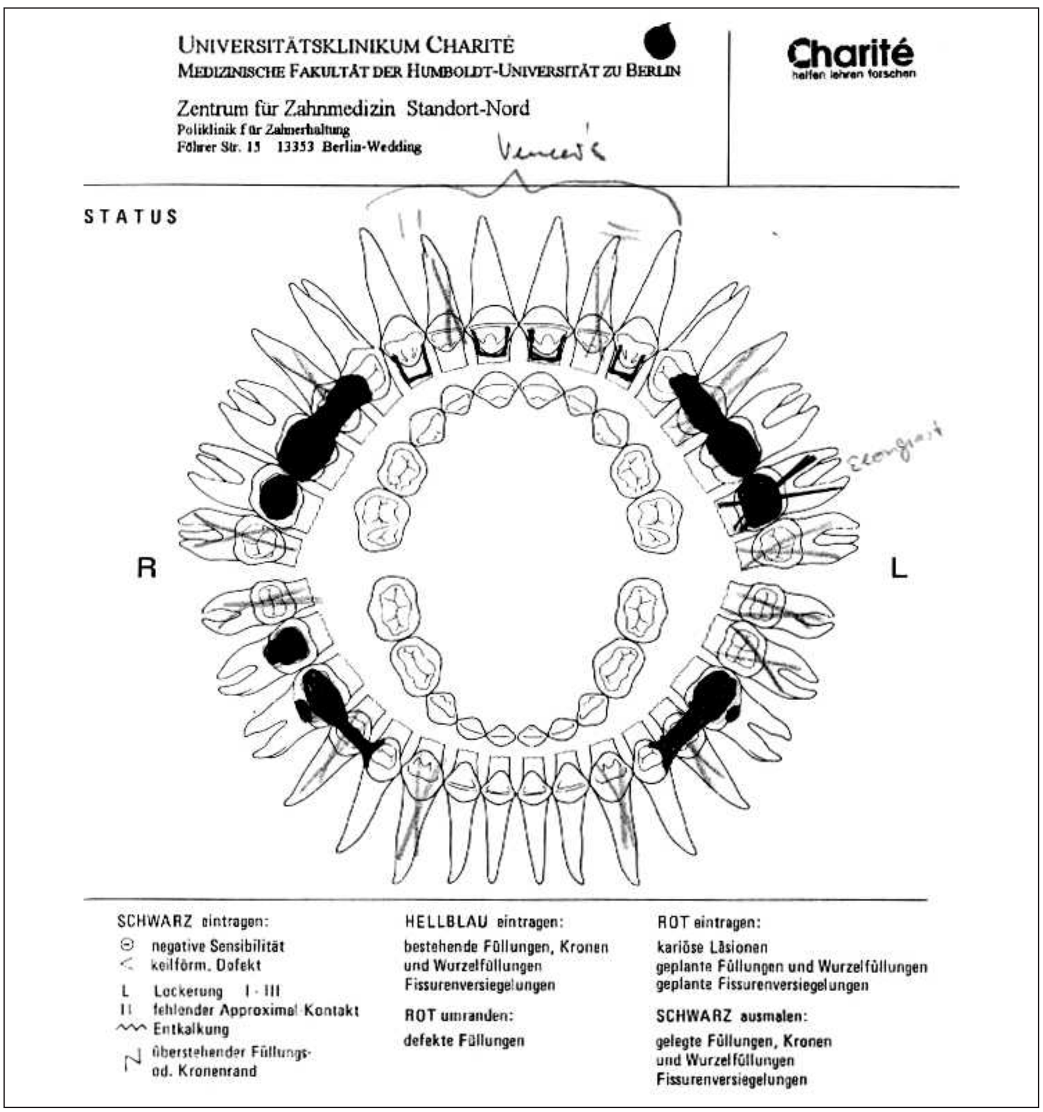

Figure 12a. *Status of patient SH. Note the absence of teeth 15, 22, 25, 35, 33, 43 and 45, which required replacement. The patient refused an implant-supported reconstruction.*

Here is a clinical case that demonstrates the possibilities dentists have in the year 2000 by using adhesive techniques. Patient SH, referred by the ortho-

Figure 12b. *Frontal view of the patient after reconstruction with ceramic veneers and bonded ceramic inlay bridges.*

Figure 12c. *Maxillary view of the patient after reconstruction with ceramic veneers and bonded ceramic inlay bridges.*

Figure 12d. *Mandibular view after reconstruction with bonded ceramic inlay bridges.*

Figure 12e. *The first and fourth quadrant: side view.*

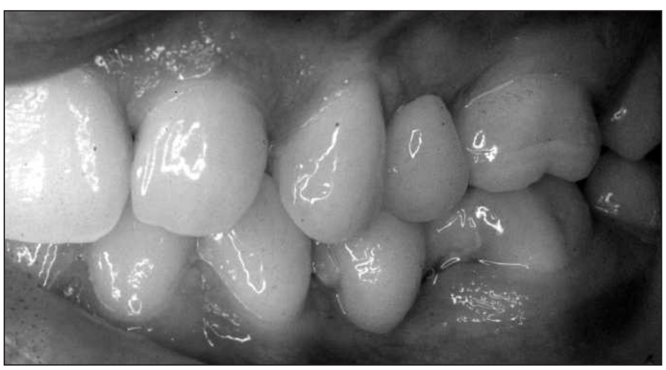

Figure 12f. *The second and third quadrant: side view.*

dontist requested improving the aesthetics and function that were no longer possible through orthodontics. She had several missing and malpositioned teeth (Figure 12a). She was treated with veneers in the anterior maxilla to give the illusion of regular teeth (enlarging the central incisors, converting the canines into lateral incisors and converting the premolars into canines). The missing premolars were reconstructed by inserting resin bonded full ceramic bridges (Empress II, Ivoclar, FL-9494 Schaan, Liechenstein) (Figure 12b-f).

A LOOK INTO THE FUTURE

Dentistry in the very near future will move toward evidence-based procedures. Since restorative dentistry has reached a very high quality level in the last decade, the longevity of restorations has become excellent (Tables 1 and 2). If we would only base our treatment decisions on the highest level of evidence (prospective randomized double-blind clinical studies or retrospective cross-sectional studies), dentists would be forced to behave extremely conservatively, which creates a problem in a field under constant development. Composites and adhesives are being permanently improved and refined. Therefore, one must also accept *in vitro* data as a basis for the decision to use a restorative material or procedure. *In vitro* simulations of clinical procedures are better than standard tests to determine the mechanical and physical characteristics of the materials. The latter are needed as a screening procedure in an early phase of the material development. Finding a reasonable position between innovation and conservatism is not easy.

Further along is the realization of visions this author published 12 years ago (Roulet, 1988). If there is a reliable way to chemically dissolve decayed tissue without damaging the sound structures, then one could just fill the cavity with a non-shrinking low viscous self-adhesive restorative material. Some components of this concept are already realized in a not-refined way (Carisolv, Mediteam AB, Sävedalen, Sweden) to remove the caries; flowable composites, some are in the pipeline (non/low-shrinking composites) and some are quite far away (self-adhesive resin based restorative material). Then this author also had a dream—that of using molecular biological techniques and gene technology. This should make it possible to modify the microorganisms in a carious lesion by a simple injection into the lesion so as to produce the components of dentin or enamel that would be calcified in the oral cavity later, instead of producing lactic acid, which destroys the tooth.

Major changes in our profession will come from an increased understanding of the biological principles governing life. Molecular biology offers very powerful techniques which will be used in the future to prevent oral disease. A few examples follow: Already, there are modified Streptococci that produce alcohol instead of lactic acid (Hillman & others, 2000). Researchers at the University of Florida suggest inoculating these modified microorganisms as a caries-preventive measure. They would colonize the relevant sites and prevent colonization by cariogenic microorganisms. By fully understanding the mechanisms of bacterial adhesion, one could formulate, eg, mouth rinses that change the tooth surface so that bacteria could no longer adhere to them. Formulating food additives, which occupy the adhesion sites on the tooth surface, therefore, making it impossible for microorganisms to dock on the tooth surface, are conceivable. If we go one step further, it becomes even more exciting. By modifying the salivary glands eg, with a simple injection (or by using some viruses as a vehicle) that contains the relevant information, these glands should be forced to synthesize antibodies against either Streptococci or periopathogenic microorganisms as a preventive measure against caries and periodontal disease. With the same mechanisms, anti-adhesives having the same as the above mentioned mouth rinses could be produced.

Dentistry's future will be exciting. However, it will also require dentists to completely change their view of the profession. The dentist of the future will be a medically- and biologically-trained expert of preventive care. For all those who have missed prevention or are accident victims, the dentist of the future must also become an expert in restorative care. Adhesive technology will provide the tools to do an excellent job.

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Clinical Research

Clinical Performance of Class II Restorations in Which Resin Composite is Laminated Over Resin-Modified Glass-Ionomer

YEY Aboush • H Torabzadeh

Clinical Relevance

Resin composite/resin-modified glass-ionomer open laminates appear to be as effective as resin composites when used for restoring Class II cavities.

SUMMARY

This study evaluated the one-year functioning of resin-composite/resin-modified glass-ionomer open-laminate restorations when used for restoring Class II cavities. It also investigated the effect of the thickness of the resin composite layer on the performance of such restorations.

The test restorations were made of Vitremer glass ionomer, Scotchbond Multipurpose Plus and Z100 resin composite, and the control restorations were made of Z100 with Scotchbond Multipurpose Plus. Forty pairs of restorations were placed in 40 patients aged 16 years and over. The thickness of the resin composite layer was measured both clinically and in the laboratory using a reflex microscope. The completed restorations were assessed *in vivo* and *in vitro* at baseline, six-month and one-year recalls using a modified Ryge system. The reflex microscope measurements showed that the majority of restorations had a resin composite layer of more than 1.5 mm in thickness, as intended. At one year, 37 pairs of restorations were examined. Apart from a few minor problems, all performed satisfactorily. Thus, it appears that the resin composite/resin modified glass ionomer open laminate is a suitable technique for restoring Class II cavities.

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INTRODUCTION

In recent years, there has been a marked increase in the use of resin-based materials in the restoration of posterior teeth. This is due to the increased demand for aesthetic restorations. Of the various methods available, the direct resin composite restoration is the simplest and most economical for providing posterior tooth-colored restorations.

There is also a growing concern about the possible risks of mercury toxicity associated with the use of silver amalgam restorations (Tyas, 1994). A recent survey showed that more than half of the dentists who returned questionnaires had been asked by patients to remove their amalgams due to health implications (Forsyth, Garrett & Aboush, 1996).

One major disadvantage of resin composite restorations has been the insufficient sealing of margins, which mainly relates to high polymerization shrinkage (Davidson & Feilzer, 1997). Leakage occurs especially at the gingival margins, where little or no enamel is present, and where it is technically difficult to obtain dry margins for etching. Gaps at the interface between resin composite and tooth may also result from stresses induced by mastication or thermal changes. Gap formation is a recognized factor in plaque accumulation, post-operative hypersensitivity, staining and secondary caries (Phillips, 1988).

Using dentin bonding agents and placing resin composite in increments have been suggested to reduce marginal leakage. It was reported in 1994, however, that many dentin bonding systems failed to prevent the development of marginal gaps when evaluated soon after placement of the restoration (Retief, 1994). Furthermore, up-to-date "single step" bonding agents did not produce higher bond strengths compared to their "multi-step" predecessors (Cohen & others, 1999).

Marginal leakage may lead to secondary caries formation—the main reason for the replacement of restorations (Qvist, Qvist & Mjör, 1990; Mjör, 1997). Also, it has long been believed that glass-ionomers reduce or inhibit secondary caries because of fluoride availability and their proven adhesion to tooth substance (Wilson & McLean, 1988). However, while there has been much discussion in recent years, many have failed to find any statistically significant differences in the diagnosis of secondary caries between resin composite and glass-ionomer restorations (Randall & Wilson, 1997; Mjör, 1997).

The debate continues, but the fact remains that adhesion of the glass-ionomer is most reliable; they can be placed in bulk and produce less stress on cavity walls while setting, compared with the rigid resin composites.

To take advantage of the best properties of glass-ionomers and composite resins, McLean & others (1985) recommended using the laminate technique. Although the conventional composite/glass ionomer laminate for restoring Class V cavities was regarded as reliable, in the Class II situation, this concept failed (Welbury & Murray, 1990; Knibbs, 1992). Progressive loss of the glass ionomer due to moisture sensitivity and lack of strength were the main reasons for failure.

Resin-modified glass ionomers might be the material of choice for use in laminate restorations due to their higher mechanical strength (Gladys & others, 1997) compared to the conventional material and its ability to set on command. They are also known to be less technique sensitive. Mount (1993) suggested that resin-modified glass ionomers can be used as a dentin substitute in laminate restorations and can remain exposed to the oral environment on approximal surfaces and at gingival margins (open laminate). Furthermore, van Dijken, Kieri & Carlen (1999) have recently reported that a resin-modified glass ionomer is an appropriate material for use in Class II open laminate restorations.

The trial aimed to:

a) evaluate the function of resin composite/resin-modified glass ionomer open laminate restorations when used for restoring Class II cavities; and

b) investigate the effect of the thickness of the resin composite material layer on the performance of such restorations.

As a control, similar Class II restorations using a dentin bonding agent and resin composite only were placed.

METHODS AND MATERIALS

Test (laminate) restorations were made of Vitremer glass-ionomer cement, Scotchbond Multipurpose Plus dental adhesive and Z100 resin composite (3M, St Paul, MN, 55144). The control restorations were made of Z100 resin composite and Scotchbond Multipurpose Plus. Calcium hydroxide liner was used in near exposure cases in both the test and control restorations. The resin-modified, tri-cure glass ionomer Vitremer sets by exposure to visible light. It also has two self-curing mechanisms to provide a relatively rapid set where light does not penetrate, allowing for bulk placement.

The clinical aspects of the trial took place at the University of Ghazvin, Iran. One clinician placed all the restorations. Male and female patients aged 16 years and over were chosen. They were assessed as generally healthy with no complicating medical histories. Each patient had two teeth in need of treatment. All patients were notified by letter of the objectives and risks of the trial and their consent was obtained.

The restored teeth were premolars and molars in functional occlusion but with Class II carious lesions or pre-existing restorations in need of replacement. However, only teeth with cavity preparations of medium width were included in the study. Those involving cusp replacement were not included.

The study was a controlled single blind trial. Forty pairs of teeth received the laminate and control restorations. At the time of treatment the patients were not informed as to whether the laminate or control restoration was to be placed in any particular tooth.

Immediately prior to each restorative treatment, the patients were asked whether the tooth had shown symptoms of hypersensitivity. Patients' answers were documented on a case report form. Information regarding any previous restoration in the tooth was also recorded. Teeth were treated under local anesthesia. A

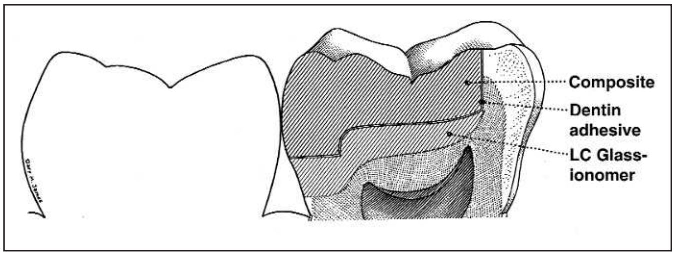

Figure 1. *Cross-sectional diagram of a typical laminate restoration.*

rubber dam was placed for all stages of the restorative procedure except for the final occlusal adjustment.

The cavity designs in both the experimental and control teeth were largely predetermined by the extent of the carious lesion or the existing restoration. Any existing restoration was "dissected" out so as not to permit any inadvertent removal of sound enamel or dentin. The cavities were modified commensurate with the removal of any existing caries or unsupported enamel. None of the cavities were extended to remove any sound fissures that extended outwards from the completed cavity preparation; rather, fissure sealant (Concise white light cured, 3M) was used. No bevelling of enamel margins was carried out. After thoroughly rinsing and drying the cavity, a metal matrix band (the only type of matrix available at the hospital) and wedge were applied.

With each laminate restoration, Vitremer primer was applied and light cured, followed by bulk packing of the Vitremer material to restore the cavity to a level approximate to that of a completed traditional base in the occlusal part of a Black's cavity, though the Vitremer was extended to the external surface of the tooth approximally (Figure 1). If necessary, the approximal part of the Vitremer was bevelled prior to applying the resin composite so that it would not form part of the contact area in the completed restoration. Burs were used to "freshen-up" the exposed enamel and dentin to ensure that no Vitremer primer was left on these surfaces.

A periodontal probe measured the depth of the remaining part of the cavity in three representative locations in two-surface cavities, and in six different locations in MOD cavities. To help determine (subsequently in the laboratory) the thickness of the resin composite layer, silicone impressions (Imprint, 3M) were made at this stage and cast with Epoxy-die (Ivoclar, Vivadent, ETS SL9494, Schaan, Liechtenstein).

To prepare the glass-ionomer surface and exposed cavity surfaces for the resin composite, phosphoric acid was applied for 15 seconds, rinsed for 15 seconds and dried. Scotchbond Multipurpose Plus Primer and Adhesive were applied per the manufacturer's instructions. The resin composite was then used to restore the contact point and complete the restoration. After removing the matrix band, the restoration was contoured and finished with finishing diamonds, strips and discs. The final restoration was checked for occlusal interferences after removing the rubber dam. Silicone impressions were made of each restored tooth and cast with Epoxy die.

To accurately measure the thickness of the resin composite layer placed in each tooth, a reflex microscope, in conjunction with a computer program, was used. At least 15 measurements were made on each model, and the minimum, maximum and average thicknesses of the composite layer were calculated.

The thickness of the Vitremer and resin composite layers were varied due to the natural variation in the morphology of the teeth, the position of their contacts with adjacent teeth and the sizes of the cavity preparations. This variation enhanced the usefulness of the study, but the intention was for the resin composite layer usually to be at least 1.5 mm at its thinnest point.

For placing the control restorations, all enamel and dentin present in the cavities were acid etched and Scotchbond Multipurpose Plus applied. Using an incremental technique, Z100 was placed, each layer being light-cured for 40 seconds. Each restoration was then contoured and finished as before, and a silicone impression was made of the restored tooth.

Completed restorations in both groups were assessed clinically using a modified Ryge system (Ryge, 1980). The quality of the restoration, with regard to retention, anatomical form, marginal integrity, marginal discolouration, color match, surface staining, surface roughness and secondary caries, was graded as Alpha (A); Bravo (B); Charlie (C). Two independent evaluators were trained to make these assessments. The evaluators were unaware of the type of any given restoration, and any discrepancy between them was resolved before the patient was dismissed.

At six months and one year post-operatively, the patients were again asked about any hypersensitivity associated with the restored teeth. Also at these recalls, silicone impressions of the restored teeth were made and the restorations were assessed clinically using the modified Ryge system. The casts produced from the impressions were also assessed by the two evaluators with regard to anatomical form, marginal integrity and surface roughness and were also graded according to the Ryge system.

The results regarding the performance of the restorations were analyzed using StatXact.3 for Windows. Two-sided McNemar's test was used to investigate the differences between the laminate and control restorations, and within each type of restoration. A level of $p<0.05$ was regarded as statistically significant.

Table 1: *Distribution of Teeth Restored*

Restoration	Premolar	Molar
Laminate	11	29
Control	17	23

RESULTS

Thickness of Resin Composite Layer

The spaces available for the composite resin component of the laminate restorations were found to be more than 1.5 mm in thickness when measured clinically using a periodontal probe. The reflex microscope measurements, carried out on the Epoxy-die models, showed that the majority of the restorations had a resin composite layer of more than 1.5 mm in thickness, but that six restorations had a resin composite layer of less than 1.5 mm thick at certain parts of the cavities.

Baseline Assessments

Thirty male and 10 female patients participated in this study. The average age was 32.1 and 23.6 years, respectively. All teeth restored were vital. CPITN scores of zero were recorded at baseline for all patients except three, for whom the maximum was two in one or more segments.

Table 1 shows the distribution of the teeth restored. For both the laminate and control restorations, molars were treated more than premolars. Table 2 shows the distribution of the tooth surfaces restored; nine laminate and seven control restorations involved both the mesial and distal surfaces of the teeth (MOD restorations). As shown in Table 3, the number of teeth with pre-existing restorations was similar for both the laminate and control restorations. Also, contiguous fissure sealant was used to the same extent for both types of restorations. Calcium hydroxide was used in four laminate restorations, while it was used in only two control restorations.

Hypersensitivity before treatment to hot, cold or sweet was observed in six laminate restorations and six control restorations. Contact points had been established in all restorations except in two control restorations, and three laminate restorations where there was no adjacent tooth or the position of the treated tooth prevented establishing a proper contact.

Table 2: *Distribution of Tooth Surfaces Restored*

Restoration	DO	MO	MOB	MOP	MOD	MODB	MODP
Laminate	13	16	1	1	8	--	1
Control	20	13	--	--	6	1	--

At baseline, only one control restoration received a Ryge Grade B (Bravo) for surface roughness; all other restorations received Grade A (Alpha) for all the criteria examined.

Six-Month Assessments

All participants except one (a recall rate of 97.5%) underwent the six-month recall examination. All teeth examined were vital and none exhibited tenderness to percussion. There were no symptoms of hypersensitivity to temperature stimuli in the restored teeth, apart from one that had a laminate restoration. The CPITN scores remained unchanged.

Summary results of the restoration-related parameters assessed are shown in Table 4. This table shows that some deterioration (from Grade A to B) was noticed for both types of restorations with regard to anatomical form, marginal integrity and color match.

One-Year Assessments

All patients who participated in the study underwent the one-year assessments except three, a recall rate of 92.5%.

All teeth examined were vital. There were no symptoms of hypersensitivity in the restored teeth and none were tender to percussion. The three positive CPITN scores noted at baseline remained at one year, but in addition, one more patient was given a score of two. No surface wear was observed clinically.

None of the restorations were lost, and there was no sign of secondary caries. There was, however, slight deterioration in some of the other criteria assessed (Table 4).

Using the McNemar's test for all possible combinations showed that none of the changes observed clinically, at both the six-month and one-year assessments, was statistically significant. This test also showed that the performance of the two types of restorations was not significantly different.

Laboratory Assessments

The results of the laboratory assessments of restorations at baseline and one-year are provided in Table 5. The McNemar's test showed there was significant deterioration in the anatomical form of both the laminate (p=0.01) and control (p=0.02) restorations revealed at one year. The test also showed a significant improvement in the surface roughness of the laminate (p=0.02) and control (p=0.01) restorations. The drop in the A grades recorded for marginal integrity (an A grade was given to restorations that adapted closely to the tooth substance) was not significant. It also showed that the differences at one year between the laminate

Table 3: *Pre-existing Restorations, Use of Contiguous Fissure Sealant and Use of Calcium Hydroxide*

Restoration	Pre-existing Restorations	Fissure Sealant	Calcium Hydroxide
Laminate	17	17	4
Control	15	18	2

and control restorations for all the three criteria assessed were not significant.

In comparing the laboratory and clinical assessments, the McNemar's test indicated a significant difference ($p<0.05$) with regard to the anatomical form assessments at one year. No other differences between the clinical and laboratory assessments were found to be significant.

DISCUSSION

The procedure used for placing the laminate restorations was relatively simple and practical. The time required to place this type of restoration was assessed subjectively as not being substantially more than that what was needed for placing a similar composite restoration. Indeed, the insertion of the glass-ionomer layer could be regarded as similar to the application of one layer of composite. However, due to the self-curing mechanism present in Vitremer, a thicker layer could be applied, thereby reducing the time required for completing the restoration.

No bevelling of enamel margins was carried out in this work, as bevelling of occlusal cavity margins makes precise finishing more difficult. It also creates problems with thin sections of marginal excess, which may be prone to fracture. Cervical bevelling may eliminate any enamel available for etching. Wilson & others (1991) reported that the performance of a composite resin did not significantly differ in butt-joint or bevel-edged preparations after five years of clinical service.

Placing resin composite layers less than 1.5 mm in thickness in some laminate restorations was not intended–the fact that it happened indicates that the clinical estimation of cavity depth can sometimes be misleading. However, having extra thin resin composite layers in some restorations may add to understanding the requirements and functioning of laminate restorations. The results indicate that restorations having less than 1.5 mm thick resin composite

Table 4: *Ryge Grades (%) Given for the Various Criteria Assessed Clinically (A = an ideal situation; B = not an ideal situation but clinically acceptable; C = clinical failure)*

Laminate Restorations

	Retention		Anatomical Form		Marginal Integrity		Marginal Discoloration	
	A	C	A	B	A	B	A	B
Baseline	100	0	100	0	100	0	100	0
6 months	100	0	97	3	97	3	100	0
1 year	100	0	97	3	95	5	100	0

	Color Match		Surface Staining		Surface Roughness		Secondary Caries	
	A	B	A	B	A	B	A	C
Baseline	100	0	100	0	100	0	100	0
6 months	90	10	100	0	100	0	100	0
1 year	89	11	97	3	100	0	100	0

Control Restorations

	Retention		Anatomical Form		Marginal Integrity		Marginal Discoloration	
	A	C	A	B	A	B	A	B
Baseline	100	0	100	0	100	0	100	0
6 months	100	0	95	5	97	3	100	0
1 year	100	0	92	8	95	5	97	3

	Color Match		Surface Staining		Surface Roughness		Secondary Caries	
	A	B	A	B	A	B	A	C
Baseline	100	0	100	0	97	3	100	0
6 months	92	8	100	0	100	0	100	0
1 year	92	8	95	5	100	0	100	0

Table 5: *Percentages of Restorations That Were Given Grade A in the Laboratory Assessments**

Criterion	Laminate Restorations		Control Restorations	
	Baseline	1 year	Baseline	1 year
Anatomical Form	83	33	80	59
Marginal Integrity	100	89	100	92
Surface Roughness	78	95	65	95

*All remaining restorations were given Grade B

layers performed well. Nevertheless, the authors do not recommend placing such thin layers of resin composite routinely until further research has been carried out in this area.

The results show that both the laminate and control restorations performed satisfactorily after one year in clinical service. Although one year is not a critical life span of modern posterior restorations, similar regimens and results were reported by other workers (Roberts & others, 1992). In addition, the majority of changes in resin composite and laminate restoration quality had been reported to occur within the first year (Stargel & Barolet, 1990; Knibbs, 1992).

The laboratory assessments of the restorations gave less favorable results compared to those obtained from the clinical assessments. This is probably due to the opaque nature of the tooth stone models and the ability to view the model from several different angles. These findings agree with those of Smales & Creaven (1985), who reported that the two indirect methods they used gave fewer good scores than the direct clinical method. It has to be stressed that no significant difference was observed between the two types of restorations even when the more discriminatory laboratory method was used to assess the restorations.

During the study none of the laminate restorations were lost, fractured or deteriorated significantly. This indicates that the laminate restoration technique may be regarded as an alternative to resin composite restorations, especially in situations where an additional caries prevention mechanism is sought.

CONCLUSIONS

1. The technique used for the placement of the Class II laminate restoration was felt to be easy and simple.

2. Clinical assessments showed no significant differences in the performance of resin composite/resin-modified glass-ionomer laminate and resin composite restorations after one year in clinical service.

3. None of the restorations required replacement, and the clinical assessments showed minimal deterioration in both types of restoration.

4. Laboratory assessments of the restorations, however, revealed significant deterioration in the anatomical form and improvement in the surface roughness of both types of restorations.

5. Laboratory assessments gave fewer A grades than the clinical assessments, and they appeared to be a more discriminatory tool compared with the clinical assessments.

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Review of Bonded Amalgam Restorations, and Assessment in a General Practice Over Five Years

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Clinical Relevance

This long-term, double-blinded clinical study was unable to substantiate that bonded amalgam restorations show fewer failures and marginal deterioration than similar restorations placed in permanent teeth using a cavity varnish lining.

SUMMARY

This study reviewed the literature on bonded amalgam restorations and assessed the failure, marginal fracture and marginal staining behavior of 366 Permite C amalgam restorations lined with five dentin bonding resins (Scotchbond 2, Panavia Ex, Amalgambond, Amalgambond Plus, Geristore) and a polyamide cavity varnish (Barrier). The restorations were placed in the posterior permanent teeth of 190 adult patients and examined at intervals over periods of up to five years. There were five restoration failures (1.4%), usually from tooth fracture, involving Class II preparations in molar teeth. No instances of persistent pulpal sensitivity or recurrent caries were reported. The marginal deterioration of the restorations was assessed indirectly using photographs for comparison with two standard sets of enlarged color transparencies. Most of the marginal fracture and marginal staining scores were low, with little difference between the six lining materials at any period.

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INTRODUCTION

Clinical studies have shown secondary caries to be the main reason for amalgam restoration replacement in general dental practice (Jokstad & Mjör, 1991). The ability to bond tooth substance to amalgam alloy could overcome several of the disadvantages of the material, allowing smaller and less macromechanically-retentive cavity preparations, and the avoidance of pins with their associated problems (Webb, Straka & Phillips, 1989; Gwinnett & others, 1994). There could also be less bulk and marginal fracture of the restorations, and a reduced marginal microleakage could lead to less tooth staining, sensitivity and secondary caries (Smales & Wetherell, 1994). The remaining tooth substance may also be reinforced, and bonding may be useful for the treatment of cracked teeth or split cusps (Trushkowsky, 1991; Bearn, Saunders & Saunders, 1994; Smales & Wetherell, 1994; Zajia & others, 1999).

Numerous *in vitro* studies of amalgam alloys bonded with various adhesives have shown increased retention and reduced microleakage compared to using cavity varnishes (Staehle, 1986; Ben-Amar & others, 1987, 1990; Cooley, Tseng & Barkmeier, 1991; Charlton, Moore & Swartz, 1992; Edgren & Denehy, 1992; Temple-Smithson, Causton & Marshall, 1992; Tjan & Li, 1992; Wetherell & Smales, 1992; Al-Moayad, Aboush & Elderton, 1993; Fischer, Stewart & Panelli, 1993; Saiku, St Germain & Meiers, 1993; Bagley, Wakefield & Robbins, 1994; Berry & Tjan, 1994; Clinical Research Associates, 1994; Eakle & others, 1994; Kawakami & others, 1994; Olmez & Ulusu, 1995; Turner, St Germain & Meiers, 1995; Berry & others, 1996; Tangsgoolwatana & others, 1997; Fritz & Finger, 1998). *In vitro* studies have also demonstrated enhanced tooth cusp strengthening from the use of bonded amalgam restorations (Christensen & others, 1991; Ianzano, Mastrodomenico & Gwinnett, 1991; Boyer & Roth, 1994; Bakland & others, 1992; Oliveira, Cochran & Moore, 1996), as well as increased acid resistance (Nakabayashi & others, 1982) and inhibition of recurrent caries-like wall lesions (Torii & others, 1989). However, the diminished adhesiveness of bonding systems after aging of amalgam-restored teeth in water and load cycling may not be effective in reducing long-term tooth fractures (Fissore, Nicholls & Yuodelis, 1991; Santos & Meiers, 1994; Bonilla & White, 1996; Pilo & others, 1996), and the value of using bonding agents to repair aged amalgam restorations appears either poor or equivocal (Mueller & Bapna, 1991; Roeder, DeSchepper & Powers, 1991; Bapna & Mueller, 1993; Hadavi & others, 1993; Nuckles, Draughn & Smith, 1994).

By contrast, apart from clinical reports on placement methods (Lacy & Staninec, 1989; Masaka, 1989; Balanko 1992; Devlin, 1993; Gwinnett & others, 1994) and short-term performances of bonded amalgam restorations (Ueno, 1989; Smales & Wetherell, 1994; Mahler & others, 1996; Belcher & Stewart, 1997; Dondi Dall 'Orologio & others, 1997; Engle & Mahler, 1997; Mach & others, 1998; Setcos, Staninec & Wilson, 1998; Summitt & others, 1999; Cannon, Tylka & Sandrick, 1999; Johnson, Browning & Gregory, 1999), there appears to be no publications of long-term prospective clinical studies in the English literature of this treatment modality. However, one retrospective study of bonded restorations, aged from 11 to 74 months, has been reported (Eakle & Staninec, 1999).

Therefore, this study tests the hypothesis that bonded amalgam restorations show less restoration and tooth-related failures, less marginal fractures or discrepancies and less marginal staining or discoloration of the adjacent tooth structure compared to similar restorations placed using a cavity varnish.

METHODS AND MATERIALS

One dentist placed 39 Class I and 327 Class II amalgam restorations in 100 premolar and 266 molar teeth of 190 informed adult patients attending a suburban general dental practice for routine dental care in Adelaide, South Australia. The 31 to 50 year age group included 62.3% of the total restorations placed. Details of the six lining materials placed beneath the restorations, and of the amalgam alloy used, are shown in Table 1. On the basis of its routine use and clinical effectiveness in the dental practice in reducing post-operative sensitivity, Barrier polyamide cavity varnish was chosen as a reference material. Copalite (HJ Bosworth Co, Skokie, IL 60076) copal-resin varnish was not used as a reference liner in this study, partly due to concerns reported regarding its lack of permanency and effectiveness with high-copper content amalgam alloys, as discussed in several publications (Chapman & Crim, 1992; Wright & others, 1992). Scotchbond 2 was also chosen for this study because it bonds reasonably well to dentin and to fresh amalgam; Panavia Ex bonds fairly poorly to dentin but reasonably well to fresh amalgam; Amalgambond and Geristore bond well to dentin and reasonably well to fresh amalgam; and Amalgambond Plus bonds well to dentin and fresh amalgam *in vitro*. (Staninec & Holt, 1988; Rueggeberg & others, 1989; Barzilay & others, 1990; Covey & Moon, 1991; Den-Mat Corp, 1991; Mueller & Bapna, 1991; Chang & others, 1992; Al-Moayad & others, 1993;

Table 1: *Materials Used*

Material	Manufacturer	Composition
Barrier cavity varnish	Teledyne Getz, Elk Grove Village, IL 60007	Dimerized oleic acid, ethylene diamine
Scotchbond 2 dentin adhesive	3M Dental Products Div. St Paul, MN 55144	Bis-GMA/HEMA
Panavia Ex luting cement	Kuraray Co Ltd Osaka 530, Japan	Phosphate ester, Bis-GMA
Amalgambond adhesive	Parkell Bio-Materials Div Farmingdale, NY 11735	4-META/ MMA-TBB
Amalgamb. Plus adhesive	Parkell Bio-Materials Div Farmingdale, NY 11735	4-META/ MMA-TBB, PMMA
Geristore resin-ionomer	Den-Mat Corp Santa Maria, CA 93456	Bis-GMA, Ba-F-Silicate glass
Permite C amalgam alloy	Southern Dental Indust Melbourne 3153, Australia	Admixture, high copper

Clinical Research Associates, 1994, 1995; Kawakami & others, 1994).

De nova cavity preparations for the restorations were confined to the extent of the carious lesions, consistent with adequate access for operative and extension for preventive measures. Repairs and replacements of previous restorations also minimized additional losses of tooth substance, consistent with the removal of any caries and previous staining along the cavity margins. Conventional cavity forms were employed when Barrier was used. Moisture control during the placement of the materials was by rubber dam or cotton roll isolation and oral evacuation. Light-cured Vitrebond (3M Dental Products Divis, St Paul, MN 55144) glass polyalkenoate (ionomer) cement base was placed in the deeper areas of all cavity preparations. Because of reports of tooth sensitivity with Panavia Ex (Masaka, 1989), Vitrebond was also placed over most of the dentin when this cement was used as the lining material. The method of application of the six lining materials is shown in Table 2.

Metal matrix bands were coated with Barrier varnish before use to reduce adhesion of the bonding materials to the bands during placement of the amalgam alloy. Following mechanical or hand condensation and carving and burnishing of the amalgam alloy, 298 of the restorations were polished at subsequent appointments using fine diamonds, plug finishing burs and abrasive-impregnated rubber cups and points (Shofu Dental Mfg Co, Kyoto, Japan). The remaining 68 restorations could not be polished shortly after their placement due to difficulties in patients being able to attend appointments.

Baseline color transparencies of the restorations were taken at 1:1.5 magnification using Ektachrome ASA 100 35 mm film (Eastman Kodak Co, Rochester, NY 14650). Similar records were also taken at recall intervals over periods of up to five years. Marginal fracture and marginal staining of the amalgam restorations were assessed blindly by both authors by comparing the photographs with two standard sets of six enlarged color transparencies, as has been described previously (Smales, 1983; Smales & Creaven, 1985). The two clinical parameters were scored from 0 to 12 on separate linear scales, where 0 represented no detection of the parameter and 12 indicated severe deterioration. Scores of 0-3, 4-8 and 9-12 approximated the alfa, bravo and charlie categories, respectively, of the USPHS-Ryge system (Ryge, 1980).

Restoration failures were assessed using the life table method, BMDP program 1L (Dixon, 1990). Differences in scores between the lining materials at each yearly interval were assessed using Kruskal-Wallis ANOVA, and differences in scores throughout the study were assessed using linear regression analysis, with Prism 2.1 software (GraphPad Software Inc, San Diego, CA 92121). Statistically significant differences between the mean scores over the study were assumed for probabilities of 0.01 or less. As a test of examiner reliability, 30 restorations originally assessed at one year were reassessed after a further three to four months.

Ethical approval for the study was obtained from the Human Research Ethics Committee of The University of Adelaide.

Table 2: *Bonding Procedures*

	Barrier	Panavia Ex	Amalgambond (Amalgamb. Plus)	Scotchbond 2	Geristore
1.	Use Vitrebond glass-ionomer cement base (lightcure 20s) in the deeper areas of the cavity preparations, but cover most of the dentin before using Panavia Ex bonding agent.				
2.	Proximal grooves	Etch enamel phosH+ 20s	Etch enamel 20s & dentin 10s with acid Activator	Etch enamel phosH+ 20s	Etch enamel phosH+ 20s
3.	Barrier varnish		rinse 20s and dry		
4.	Permite C	Mix Panavia, apply as thin coating to all surfaces	Adhesive Agent, apply to dentin 30s, blow off excess, don't dry	Scotchprep Primer, apply to dentin 60s, dry 15s, Scotchbond 2 apply all surfaces, don't thin	Mix Geristore, apply as thin coating to all surfaces
5.		Permite C	Mix Amalgambond, (and HPA powder), apply thin coating to all surfaces, don't dry	Light cure 20s	Permite C
6.			Permite C	Permite C	

Table 3: *Distribution of Lining Materials by Preparation Class and Tooth Type*

Material	Class I	Class I	Premolars	Molars	Total
Barrier	8	61	14	55	69
Scotchbond 2	4	37	14	27	41
Panavia Ex	9	71	26	54	80
Amalgambond	10	71	24	57	81
Amalgamb. Plus	3	45	11	37	48
Geristore	5	42	11	36	47
	χ^2 = 1.350, df = 5, *p*= 0.93		χ^2 = 4.810, df = 5, *p*>= 0.44		

Table 4: *Marginal Fracture Scores by Yearly Intervals*

	Interval (years)				
Material	0-1	1-2	2-3	3-4	4-5
Barrier	1.8±1.2	2.3±1.7	2.3±1.0	2.8±1.1	2.7±0.9
N=	78	16	24	14	22
SB2	2.1±1.3	1.9±1.0	2.6±0.7	3.3±2.1	2.9±0.7
N=	44	15	17	12	15
PanEx	2.1±1.1	2.3±1.0	2.4±1.2	2.5±1.5	2.5±1.2
N=	85	38	40	32	29
AmalB	1.7±1.1	1.6±0.9	2.1±1.5	1.5±1.2	2.2±1.3
N=	99	31	30	29	37
AmalBP	1.0±0.9	1.6±1.2	2.4±2.2	2.3±1.8	1.9±1.4
N=	53	20	18	12	24
Gerist.	1.4±0.9	2.0±1.2	2.5±1.0	1.7±1.4	2.9±1.9
N=	51	17	13	11	13
Kruskal-Wallis ANOVA					
Statistic	36.7	12.4	4.6	14.8	7.1
P value	<0.001	0.03	0.47	0.01	0.22

Mean ± Standard Deviation. N = observations

RESULTS

No significant differences were present in the baseline distribution of the six lining materials by dental arches, preparation class and tooth type (Table 3), restoration polishing, patient age groups and smoking and oral hygiene habits ($p>0.10$). Of the 327 Class II amalgam restorations, 178 involved cusp coverage, of which seven had additional pin retention.

There were five true failures and one unrelated or apparent failure in molar teeth with Class II cavity preparations. The overall restoration failure rate was low at 1.4%, but with a borderline possibility of significantly higher failures involving Scotchbond 2 (Mantel-Cox statistic = 11.633, df = 5, P = 0.04). Cumulative survival percentages were 100 ± 0 (Standard Error) for Barrier, Amalgambond Plus and Geristore, 98 ± 2 for Amalgambond and Panavia Ex, and 87 ± 7 for Scotchbond 2. Three restored teeth bonded with Scotchbond 2 and one bonded with Panavia Ex fractured. One very large restoration bonded with Amalgambond was lost. No failed restorations were associated with persistent pulpal sensitivity or recurrent caries. The 16 instances of mild post-insertion pulpal sensitivity reported following the questioning of patients were short-term and not material related.

The mean scores for the observations of amalgam deterioration over five years for the six lining materials are shown in Tables 4 and 5. There were no instances of unsatisfactory rating scores, with most scores being low (0-3) and approximately equivalent to USPHS ratings of alfa. Very few statistically significant differences were found between any of the six lining materials at any observation period for the marginal behavior of the restorations. Only for marginal fracture at 0-1 years was the mean score for Amalgambond Plus significantly higher than for Scotchbond 2, Panavia Ex and Barrier ($p<0.01$). Linear regression analysis for marginal fracture over time showed no significant differences in the slopes among the six lining materials ($p>0.03$). Similar results were found for marginal staining ($p>0.10$).

Complete agreements between the original and duplicate rating scores were 40% for each of the two clinical parameters assessed. However, apart from two instances, all duplicate scores were within two points of the original scores, and there were reasonable intra-examiner agreements found, with a weighted Kappa of 0.58 for marginal fracture and 0.82 for marginal staining.

DISCUSSION

Placement

The six lining materials were originally intended to be used sequentially, but relatively more Barrier, Panavia Ex and Amalgambond linings were placed than were the other materials. However, there were no significant differences in the distribution of the materials when analyzed for numerous clinical parameters ($p>0.10$).

Table 5: *Marginal Staining Scores by Yearly Intervals*

	Interval (years)				
Material	0-1	1-2	2-3	3-4	4-5
Barrier	2.5±1.6	3.1±1.4	3.5±1.0	3.7±0.7	3.3±0.8
N=	78	16	25	14	22
SB2	3.0±1.3	3.5±1.4	3.5±1.1	3.0±1.2	3.5±1.3
N=	44	15	17	12	15
PanEx	2.5±1.6	3.1±1.3	3.4±1.5	3.1±1.5	2.6±1.7
N=	85	38	40	32	30
AmalB	2.6±1.9	3.0±1.5	3.1±1.4	2.3±1.6	2.8±1.5
N=	99	31	30	29	37
AmalBP	2.9±1.7	2.1±1.6	2.5±1.7	2.5±1.8	2.3±1.5
N=	53	20	19	12	24
Gerist.	3.1±1.5	3.1±1.3	3.4±0.9	2.3±1.7	2.9±1.4
N=	51	17	14	12	13
Kruskal-Wallis ANOVA					
Statistic	16.2	6.6	5.6	11.7	8.1
P value	<0.01	0.25	0.35	0.04	0.15

Mean ± Standard Deviation. N = observations

As reported previously (Wetherell & Smales, 1992), Panavia Ex was viscous and sticky to handle, and Amalgambond set very fast. The application of the bonding materials was time-consuming with smaller preparations, taking around 1 3/4-2 1/4 minutes longer, costing more than placing Barrier cavity varnish, and also requiring careful moisture control.

Failures

There were very few restoration or tooth-related failures and, although the use of Scotchbond 2 was associated with more failures than for the other lining materials (p= 0.04), the numbers were too few to imply any clinical significance. Several other clinical studies reported no failures for bonded restorations over the periods from 18 to 48 months (Wetherell & Smales, 1994; Belcher & Stewart 1997; Dondi Dall 'Orologio & others, 1997; Johnson & others, 1999; Summitt & others, 1999). Generally, in the permanent dentition, when failures did occur, no significant differences were found between bonded and non-bonded/pinned amalgam restorations, small or large, either in clinical trials (Mahler & others, 1996; Setcos & others, 1998) or in a retrospective study (Eakle & Staninec, 1999). However, in the primary dentition, Class II bonded amalgam restorations performed significantly better over three years than non-bonded restorations that failed from isthmus fracture and recurrent caries (Cannon & others, 1999). None of the bonded amalgam repairs failed in the present study, despite the poor *in vitro* bonding strengths reported (Mueller & Bapna, 1991; Roeder & others, 1991; Bapna & Mueller, 1993; Hadavi & others, 1993; Nuckles & others, 1994). It has been shown that both cusp-covered and more conservative amalgam restorations placed without adhesive bonding materials in permanent teeth can have high survival rates with minimum tooth morbidity (Smales & Hawthorne, 1996, 1997), and using adhesive materials may offer few long-term clinical advantages.

There were no restoration failures from caries; patients also reported no instances of persistent pulpal sensitivity. Although polyalkenoate (ionomer) bases were placed in the deeper cavities, Amalgambond has also been shown to lead to a significant reduction of sensitivity when applied to cervical tooth surfaces (Calamia & others, 1992). As with dentin bonding materials, using Barrier cavity varnish has led to significantly less microleakage, with a reduction of recurrent caries-like lesions at the root surface margins of amalgam restorations when compared with using no sealer (Hummert, Chan & Osborne, 1992). Filled resin adhesives have shown less microleakage (St Germain, Sites & Meiers, 1998) and higher bond strengths (Bagley & others, 1994; Kawakami & others, 1994; Clinical Research Associates, 1995) than unfilled adhesives *in vitro* and may help dissipate mechanical and thermal stresses on the restored teeth.

Several clinical trials have investigated the occurrence of short- and long-term post-operative sensitivity following the placement of bonded amalgam restorations (Browning, Johnson & Gregory, 1997; Kennington & others, 1998; Gordon & Mjör, 1999). These studies, and others mentioned by the authors, failed to demonstrate any advantages of adhesive liners over traditional cavity varnishes or bases in reducing sensitivity. But the use of an amalgam-bonding base, combined with a dentin adhesive, may possibly be more effective than using an adhesive alone (George & Barnes, 1998).

Deterioration

Marginal fracture deterioration of the high-copper content amalgam alloy was low and fairly similar for all six lining materials. There was no statistically significant evidence of a "decreased edge fracture" for the amalgam restorations placed with Amalgambond (Masaka, 1989). It is unknown to what extent different cavity varnishes and thicknesses influence marginal fracture, and the existing clinical data are sparse and inconclusive (Jokstad, 1992). Other clinical trials over periods ranging from 12 to 42 months (Smales & Wetherell, 1994; Mahler & others, 1996; Belcher & Stewart, 1997; Engle & Mahler, 1997; Mach & others, 1998; Setcos & others, 1998; Johnson & others, 1999), and a retrospective study over periods up to 74 months (Eakle & Staninec, 1999), have also reported low and fairly similar marginal deterioration for both bonded and non-bonded amalgam restorations. Only one clinical trial over three years, involving cusp-covered complex amalgams, has found significantly less marginal fractures with bonded, compared with non-bonded, amalgam restorations (Summitt & others, 1999). However, marginal fracture as a predictor of amalgam restoration survival can be an unreliable indicator (Smales & others, 1991).

Although amalgam alloy metallic discoloration of tooth structure is unattractive and not uncommon, there have been few reports concerning marginal staining with bonded restorations (Smales & Wetherell, 1994). In this study, Barrier showed a more rapid rate of deterioration for marginal staining than did the other lining materials, although the scores were generally low and not significantly different. This trend may relate to a lack of initial mechanical adhesion for Barrier at the amalgam/tooth interface, as well as to possible, subsequent hydrolytic degradation of the polyamide varnish (Hack & Thompson, 1993). The low corrosion rates of high-copper content amalgam alloys results in little tooth discoloration, even without cavity varnish (Smales & Rupinskas, 1991).

CONCLUSIONS

In this clinical study of amalgam restorations placed in permanent teeth, the six lining materials evaluated over periods of up to five years found:

1. few restoration or tooth-related failures (1.4%), with no instances of caries or persistent post-insertion pulpal sensitivity.

2. marginal fracture and staining scores were generally low and similar among the six lining materials.

3. using adhesive lining materials may offer few long-term survival advantages over non-bonded, high-copper content amalgam restorations.

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Cervical Compomer Restorations: The Role of Cavity Etching in a 48-Month Clinical Evaluation

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Clinical Relevance

This 48 month follow-up demonstrated that enamel and dentinal etching improves long-term marginal adaptation of compomer restorations in Class V cavities.

SUMMARY

Compomers are defined as polyacid-modified resin composites. They are supposed to combine the advantages of traditional glass-ionomer cements with resin composites.

This study clinically evaluated a compomer in cervical cavities. Sixty cervical cavities in premolars and molars (24 with cervical caries and 36 with abrasions) randomly divided into two groups of 30 teeth (Group 1 and Group 2) were restored with Dyract (DeTrey-Dentsply, York, PA 17405-0872). The cavities of Group 2 were etched for 30 seconds with orthophosphoric acid before compomer application, while the Group 1 cavities received no treatment. All the restorations were evaluated every six months, up to 48 months: characteristics assessed according to USPHS-modified standards were retention, secondary caries, post-operative sensitivity, marginal adaptation and discoloration, color and wear. The Kaplan-Meier's survival analysis was performed.

In both groups, retention was high without any statistically significant difference. No difference was found between the two groups for caries, post-operative sensitivity and wear—that all had a low incidence. Color was not perfectly matched, however, there was no statistically significant difference between the two groups. Marginal discoloration and marginal adaptation loss were significantly higher in non-etched group ($p<0.05$). Clinically relevant failure required 17.2% of restorations in the non-etched group and 10% in the etched group to be replaced: this difference was not statistically significant.

Dyract has an acceptable clinical behavior when used in cervical cavities. Its marginal adaptation is enhanced by etching.

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INTRODUCTION

Caries prevalence reduction, together with higher esthetic needs, have increased research and led to the development of new materials in an attempt to combine the advantages of resin composites to those of glass-ionomer cements (Nicholson & Croll, 1997). On the basis of McLean classification (McLean, Nicholson

& Wilson, 1994), they are divided into resin-modified glass-ionomer cements and polyacid-modified resin composites; several products are included in the first group, supplied with a radio-opaque fluoride-alumina-silicate powder and a liquid component containing 2-hydroxyethyl-methacrylate (HEMA), water and a photoinitiator. Cement setting, due to an acid-base reaction, starts after the two components are mixed together. Light exposure causes the creation of cross bonds between polymeric chains and simultaneous polymerization of methacrylate. Benefits correlated to this kind of materials are represented by increased manipulation time, lower setting time and sensitivity to humidity and drying; mixing procedures and polishing are also improved (Al-Obaidi & Salama, 1996; Sidhu, Sherriff & Watson, 1997).

Polyacid-modified resin composites differ from the previous for the predominant resinous content, while the acid-base reaction, even if present, is not sufficient to determine the cement setting in absence of light exposure. The majority of the authors consider these materials, named compomers, more similar to resin composites than to GICs (McLean & others, 1994; Christensen, 1996; McCabe & Walls, 1998).

Compomers are essentially resin-matrix composites where the usual insert filler has been replaced by an ion-leachable aluminosilicate glass (McCabe & Walls, 1998). Light exposure determines a free radical reaction responsible for developing a three-dimensional structure reinforced with the filler and of the improved bonding with the adhesive's monomers. In some materials, the resin also contains acidic groups that possibly generate an acid-basic reaction with the glass component (McCabe & Walls, 1998), although it inadequately produces a complete material setting by itself (Maneenut & Tyas, 1995; Gladys & others, 1997). It is thought that the acid-base reaction may enable the surface of the glass particles to react in order to liberate fluoride (McCabe & Walls, 1998). Fluoride content is about 10% and its release is estimated at 6-7 ppm per month (Forsten, 1995).

In vitro mechanical properties are superior to those of traditional GIC and resin-modified GIC, but cannot achieve the levels of resin composites for posterior teeth (Gladys & others, 1997). Polymerization contraction (estimated at 3% in volume) is partially balanced by water absorption during the acid-base reaction and do not seem to produce marginal microleakage even if some authors demonstrated that compomer restorations are lacking in their marginal adaptation (Brackett & others, 1998).

Compomers' clinical use has been improved by applying a conditioner provided by the manufacturer as a unique product that combines the properties of a sealer and a light-curing dentinal adhesive. Some authors have hypothesized using compomers without the primer-adhesive as proposed by the manufacturer, but experimental tests demonstrate that the best results are obtained with a combined application (Elderton & others, 1996).

In order to produce effective bonding, it has been suggested that compomers must essentially be treated as composites. Dental etching has been proposed before primer application, demonstrating three time higher bonding values to enamel (Forsten, 1995).

Based on this, compomers in conservative dentistry are indicated for definitive Class III and cervical restorations, temporary treatment of occlusal and proximal cavities in caries-susceptible subjects and as restoration material in primary teeth, combining GIC benefits (fluoride release, even if not high, and tissue adhesion) to those of composites, as manipulative characteristics and chemical-physical properties.

Adequate long-term follow-up is not yet available due to recent commercial introduction of these materials. This study aimed for the medium and long-term follow-up of Dyract in cervical cavities and the evaluation of etching effectiveness on the clinical behavior of this material, comparing etched cavities to non-etched ones.

METHODS AND MATERIALS

Sixty cervical restorations in 44 patients (mean age 49.3, age range 29-71) were placed by the same operator in permanent teeth (34 molars and 26 premolars) of both dental arches (32 mandibular and 28 maxillary): 24 teeth presented cervical caries, while 36 teeth were treated for abrasions. Thirty-eight patients had only one restoration, eight patients had two restorations and two patients had three restorations. The coronal margin of each cavity was placed at the enamel level, while the cervical margin was placed in the cementum.

Teeth were randomly divided into two groups of 30 each (Group 1—non-etched and Group 2—etched), using a strictly alternated distribution criteria both for caries and abrasions (in each group there were 12 caries and 18 abrasions). The mean age was 52.4 and 46.2 in Group 1 and Group 2, respectively.

The restorations were placed using the technique proposed by the producer based on the following steps:

- Cavity preparation with removal of decayed tissue in carious lesions without creating additional mechanical retention.
- Cavity cleansing and isolation of the working area with a rubber dam; a cavity liner/base was not applied in any case.
- Etching for 30 seconds, washing and drying (only in Group 2).
- Primer-adhesive application (Dyract-PSA, DeTrey-Dentsply, York, PA, 17405-0872), distributed with an air blast and light-cured for 10 seconds, after 20 seconds of action.

Table 1: *USPHS Modified Standards*

	Retention
Alpha	Complete retention of the restoration
Bravo	Mobilization of the restoration, still present
Charlie	Loss of the restoration
	Secondary caries
Alpha	Absence of secondary caries
Bravo	Presence of secondary caries
	Marginal discoloration
Alpha	Absence of marginal discoloration
Bravo	Presence of marginal discoloration, limited and not extended toward the pulp
Charlie	Evident marginal discoloration, penetrated toward the pulp chamber
	Marginal adaptation
Alpha	Absence of discrepancy at probing
Bravo	Presence of discrepancy at probing, without dentin exposure
Charlie	Probe penetrates in the discrepancy, with dentin exposure
	Post-operative sensitivity
Alpha	Absence of dentinal hypersensitivity
Bravo	Presence of mild and transient hypersensitivity
Charlie	Presence of strong and intolerable hypersensitivity
	Color
Alpha	Restoration is perfectly matched for color and shade
Bravo	Restoration is not perfectly matched for color and shade
Charlie	Restoration is unacceptable for color and shade
	Wear
Alpha	Restoration is a continuation of the anatomic form; it may be in excess
Bravo	Significant loss of the superficial material, without dentin exposure
Charlie	Significant loss of the material, with dentin exposure

- A second application of the primer and immediate polymerization.
- Incremental compomer placement (in 2 mm layers or less) and polymerization of each layer for 40 seconds; the last layer applied was always the cervical one.
- Immediate finishing and polishing.

Restorations were evaluated at the end of the first session and every six months up to 48 months for retention, secondary caries, marginal discoloration, marginal adaptation, subjective post-operative sensitivity, color and wear. Each aspect was evaluated independently by the other two authors according to USPHS (United States Public Health Service) modified standards (Cvar & Ryge, 1971) (Table 1): in case of disagreement, a consensus was achieved.

The Kaplan-Meier's analysis was performed to calculate the survival rates relative to the different evaluation characteristics to estimate the time that occurred between the placement of the restoration and its end (failure, withdrawal or censure) (Papathanasiou, Curzon & Fairpo, 1994). Withdrawal included patients lost to follow-up and teeth with caries on different surfaces. Censored restorations were those recorded as intact for each single aspect until the end of the study.

The two groups were statistically compared using the Log-rank test: the statistical analysis was performed for each characteristic assessed at every control step.

Table 2: *Recall Rates for Patients at Each Evaluation*

Recall	**Group 1**	**Group 2**
6 months	97	97
12 months	97	97
18 months	97	97
24 months	93	97
30 months	90	93
36 months	87	90
42 months	87	83
48 months	77	73

The clinical relevance of failures was determined as the need for restoration replacement; restorations should be replaced whenever a Charlie score was recorded except for caries and retention, which occurred with a Bravo score. The Kaplan-Meier's analysis was carried out on these data to obtain a survival curve on the basis of failed (need for replacement), withdrawn and intact restorations.

RESULTS

Table 2 summarizes recall rates for the patients at each evaluation. Figure 1 reports the percentage of Alpha-scored restorations at 48 months. At 48 months teeth withdrawn because of patient drop-out, caries on different surfaces or tooth extraction were 20% in non-etched group and 26.7% in etched group. These cases, as long as present in the study, were included in the global number of restorations assessed.

The survival analysis on retention (Figure 2) showed that no restoration was lost in the first 24 months in both groups. Between 24 and 48 months, the lost restorations were 13.3% in the non-etched group and 10% in the etched group: this difference was not statistically significant. As for withdrawn teeth, these restorations, as long as present *in situ*, were counted in the evaluation of secondary caries, post-operative sensitivity, wear, color, marginal discoloration and adaptation.

Secondary caries (Figure 3) and post-operative sensitivity (Figure 4) were absent in the etched group, while their incidence in the non-etched group was low (6.7% in both cases): there was no statistical significance, anyway. The two cases of secondary caries developed at 48 months. Patients referred that the sensitivity perceived was slight.

The wear (Figure 5) was irrelevant, with the same incidence in both groups (6.7%).

The color (Figure 6) of many restorations (36.7% in the non-etched group and 26.7% in the etched group)

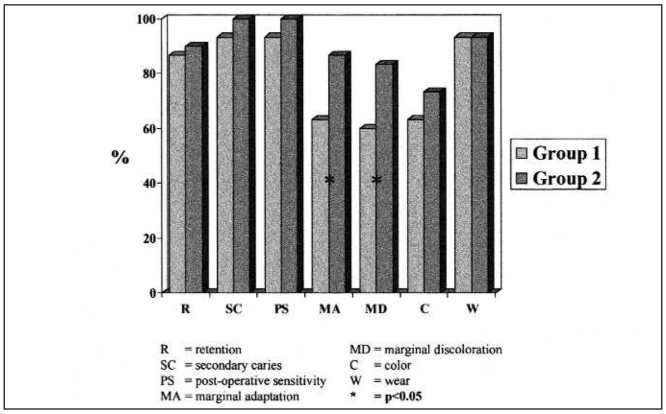

Figure 1. *Percentage of Alpha restorations at 48 months in Groups 1 and 2.*

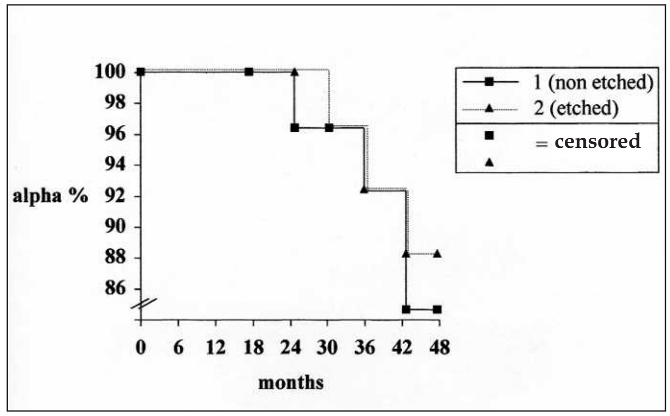

Figure 2. *Retention: survival curve at 48 months.*

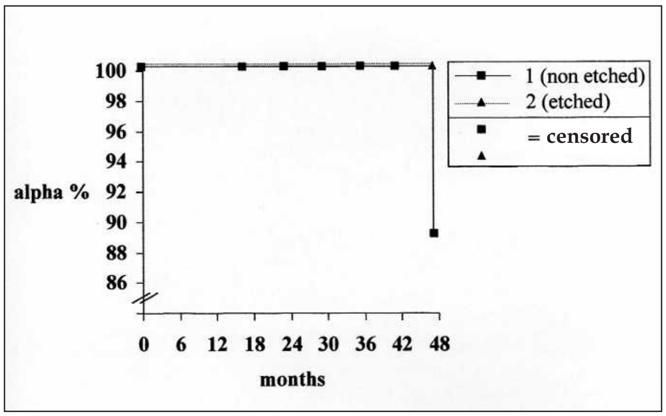

Figure 3. *Secondary caries: survival curve at 48 months.*

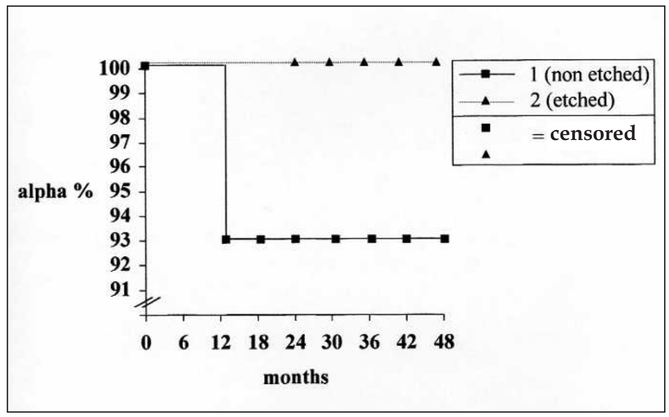

Figure 4. *Post-operative sensitivity: survival curve at 48 months.*

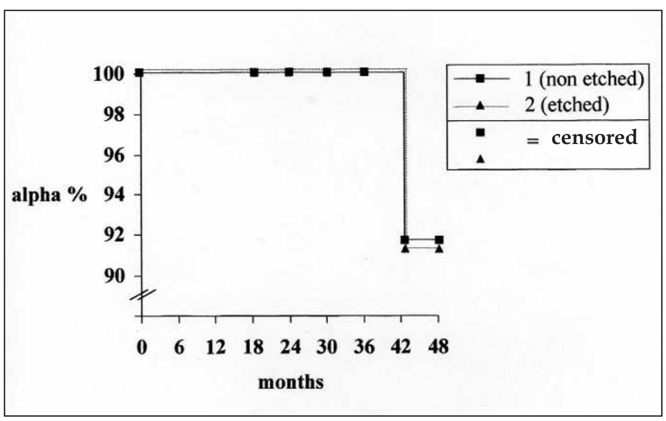

Figure 5. *Wear: survival curve at 48 months.*

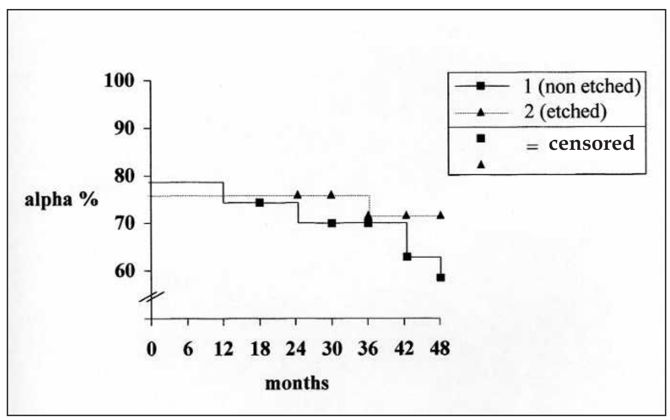

Figure 6. *Color: survival curve at 48 months.*

did not perfectly match with the shade of the teeth, but there was no statistically significant difference between the two groups. This aspect was evident from the beginning of the study (failed restorations at time 0 were 20% in the non-etched group and 23.3% in the etched group).

Marginal discoloration (Figure 7) and loss of marginal adaptation (Figure 8) were high in the non-etched group (40% and 36.7%, respectively), with a statistically significant difference if compared to the etched group (16.7% and 13.3%, respectively) ($p<0.05$).

Figure 9 represents the survival curve obtained considering the need for restoration replacement in order to determine the clinical relevance of the failure of each variable evaluated. In the non-etched group, 17.2% of the restorations needed to be replaced; the mean survival time was 46 months, while within the failed restorations, the mean age of replacement was 38

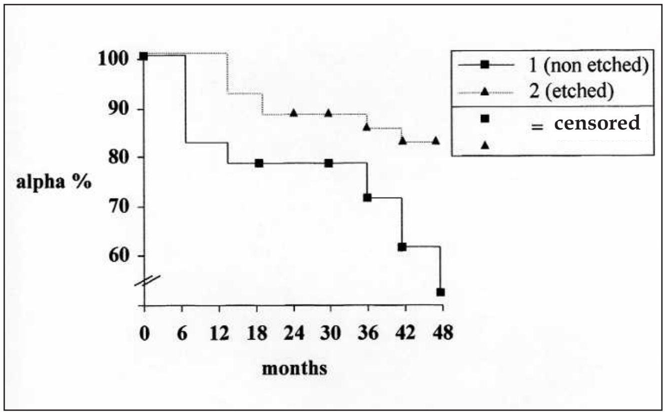

Figure 7. *Marginal discoloration survival curve at 48 months.*

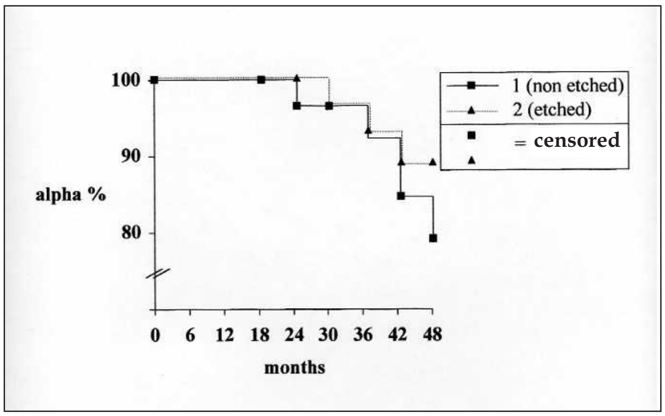

Figure 9. *Restorations replaced for clinical failure: survival curve at 48 months.*

months. In the etched group, the restorations replaced were 10%, with a mean survival time of 47 months and a mean replacement age of 36 months for failed restorations. In the non-etched group, the restorations were replaced for secondary caries or loss of retention; in the etched group, the reason for replacement was only the retention loss: no restoration was replaced for failure of the other aspects evaluated. There was no statistically significant difference between the two groups.

DISCUSSION

Retrospective data are often presented to estimate the longevity of compomer restorations, but there are few long-term prospective clinical trials. A four-year follow up, as in this work, can be considered adequate for a significant evaluation.

Dyract is a material that is easy to use and when employed with an adhesive, it allows smaller cavities to be prepared without mechanical retention. The good interface between tooth and compomer is responsible for the low incidence of secondary caries, also partially ascribed to fluoride release, as reported in literature (El-Kalla & García-Godoy 1999).

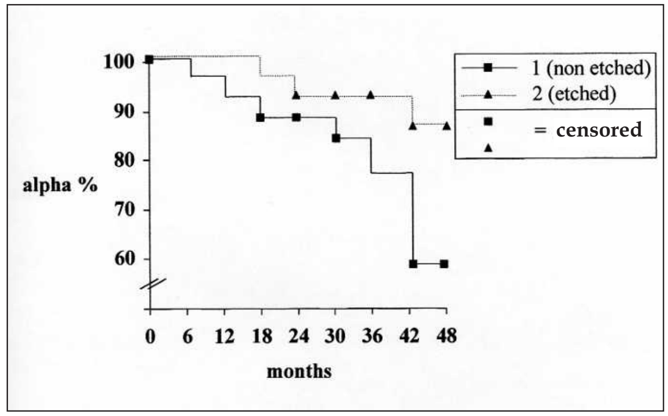

Figure 8. *Marginal adaptation: survival curve at 48 months.*

This clinical study confirmed these good properties; the incidence of secondary caries was low and the wear of the material, a frequent reason of clinical failure when Dyract is used in stress-bearing cavities (Peutzfeld, García-Godoy & Asmussen, 1997; Sepet, Aytepe & Oray, 1997), was not relevant in this evaluation of cervical restorations.

Many restorations did not match well with the color of teeth. This was evident from the beginning of the study; this aspect is ascribed to the lower aesthetic properties of compomers and to the Dyract's limited shades available at the beginning of the study compared to composites.

The manufacturer suggests that tooth etching is unnecessary for most restorative procedures with Dyract. Although the recommended primer is considered adequate to condition tooth-hard tissues, it has been demonstrated that compomer restorations are lacking in their marginal adaptation (Brackett & others, 1998; Tyas, 1998).

To further improve the tooth-compomer interface, we modified the manufacturer's protocol introducing etching. The good retention showed by restorations of both groups did not appear to be improved by cavity etching, while marginal adaptation loss and discoloration were significantly higher in the non-etched group. Presumably, dentin adhesion is mainly relevant to restoration retention and using etching does not seem to increase the effective bond obtained with the recommended primer. On the other hand, enamel adhesion is mainly relevant to marginal adaptation and discoloration. The slight acid content of the primer is probably inadequate to achieve a suitable conditioning of the enamel, and etching is required to produce effective bonding. Nevertheless, 16.7% of restorations of the etched group showed discoloration at 48 months, a clear sign of initial failure of restoration adhesion. Perhaps superior results could be obtained using compomers in association with the most recent adhesive systems. These may further increase the adhesion of the material.

In this study, the separate results with carious and noncarious lesions were not evaluated. A further analysis might be necessary to point out the different clinical behavior of the restorations placed in cavities of a diverse nature.

A modified formulation of the compomer is now available (Dyract AP, DeTrey-Dentsply, York, PA, 17405-0872), based on a greater resinous content and, therefore, more similar to composites. These properties probably impart improved mechanical characteristics but may also be responsible for a reduction in fluoride release (McCabe & Walls 1998) and subsequent enhanced risk of secondary caries. However, the introduction of this new material is too recent to evaluate its clinical behavior. Although the manufacturer still considers etching unnecessary even for this new material, based on our study, we believe that etching should always be performed to achieve compomer restorations' clinical success.

CONCLUSIONS

This study demonstrated that Dyract has an acceptable long-term clinical behavior when used in cervical cavities. The marginal adaptation of the material is significantly improved by cavity etching that should be always performed, even though the manufacturer considers it unnecessary.

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Laboratory Research

Fracture Resistance of Five Pin-Retained Core Build-Up Materials on Teeth With and Without Extracoronal Preparation

FJT Burke • AG Shaglouf
EC Combe • NHF Wilson

Clinical Relevance

Amalgam core build-ups may provide the greatest resistance to fracture on teeth prior to preparation, but the strength of the amalgam core is reduced following preparation for a crown. When amalgam is used as a core build-up material, care should, therefore, be exercised to minimize the extent of the subsequent preparation if resistance to fracture is to be maximized. Prepared core build-ups in hybrid composite provided the highest fracture resistance.

SUMMARY

Core build-ups should provide satisfactory strength and resistance to fracture both before and after crown preparation. This paper examines the resistance to fracture of core build-ups in different materials and the fracture resistance of core build-ups when these have been reduced for full crown preparation. Standardized core build-ups were made on groups of extracted molar teeth of similar size, with 10 teeth per group. Three resin-composite (Prisma APH: Dentsply, Weybridge, UK; Ti-Core, Essential Dental Systems, NJ, US and Coradent, Vivadent, Liechtenstein), one cermet (Ketac-Silver, ESPE GmbH, Seefeld, Germany) and one amalgam material (Duralloy, Degussa Ltd, Cheshire, UK). These specimens were subjected to compressive force on a universal testing machine and the force at fracture noted. Standardized full crown preparations were made on a further five groups of core build-up specimens using the same materials as above. These prepared specimens were subjected to compressive force on a universal testing machine and the force to fracture noted. The results indicated that amalgam core build-

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ups demonstrated higher fracture resistance than the other materials examined. There was a general decrease in the fracture strength of the specimens following crown preparation, with the teeth restored with the amalgam core build-ups showing a greater percentage reduction in fracture strength than the other materials tested. Prepared core build-ups in a hybrid composite material provided the highest fracture resistance. The cermet material used provided the lowest resistance to fracture in both the core build-up and crown preparation specimens. In terms of fracture resistance, no advantage was apparent in using the two composite materials designated as being specifically appropriate for core build-ups.

INTRODUCTION

The fracture of cusps of posterior teeth has been considered to be a common clinical occurrence (Lagouvardos, Sourai and Douvitsas, 1989), with management of a tooth following cuspal fracture often involving the placement of a crown, many of which are placed to prevent future tooth fracture (Bader, Shugars & Robertson, 1996). However, before a crown is placed for the restoration of a fractured tooth, often it may be necessary to complete a core build-up (foundation) restoration to provide adequate resistance and retention form for the crown preparation. Apart from acting as a transitional restoration in the management of the damaged tooth, a core build-up restoration must withstand the rigors of crown preparation and impression procedures and, therefore, initially contribute to the retention and support of a temporary crown, and in the long term, the definitive extra-coronal restoration. In this function, the core build-up generally transmits axial loads to the remaining tooth tissues and contributes to the resistance and distribution of laterally applied loads.

Tooth fracture resistance has been established as an appropriate method of investigating tooth strength (Burke, 1992), and as a comparative test for core build-up restorations in posterior teeth (Tjan, Dunn & Lee, 1993: Burke, Wilson & Watts, 1993: Santos & Meiers, 1994). While such testing has certain limitations, it is of value in ranking restorative dental materials regarding their ability to restore the fracture resistance of prepared teeth (Jagadish & Yogesh, 1990).

The study aimed to:

(i) investigate and compare the fracture resistance of permanent molar teeth restored with core build-ups of appropriate materials.

(ii) assess the effect of preparation of the core build-up for a full coverage crown on the fracture resistance of the specimens restored with the different core-build up materials.

METHODS AND MATERIALS

Tooth Selection

Recently extracted, intact or essentially intact lower third molar teeth of average size and morphology were selected for this study. Given the difficulties in obtaining a substantial number of intact lower first and second permanent molar teeth, lower third molars were used.

The teeth collected for the study were carefully examined under a stereomicroscope (X10 magnification) with the aid of transillumination to eliminate any teeth with defects, including cracks. Any tooth that had been allowed to dry out following extraction or had been stored in a fixative or disinfection solution for more than 24 hours was rejected. The selected teeth were cleaned with pumice and water and stored in tap water at room temperature (22°C) prior to testing, except for those stages of the restorative procedures requiring drying of the tooth surface.

To reduce the effect of variation in tooth size on fracture resistance in this study, a large number (>120) of sound lower third molar teeth were collected. The bucco-lingual width (BLW) of each individual tooth was measured at the maximum convexity of the tooth with the aid of Vernier calipers and a mean value for BLW calculated (10.06 mm). One hundred and ten teeth were then selected for inclusion in the study, provided the BLW of each tooth did not differ by more than 2.5% from this mean value. Teeth were then divided into 11 groups of 10 with the proviso that the 110 teeth selected had a BLW variability of 5% around the mean and that there was no more than 2.5% variation in BLW within any group.

Test Groups and Materials

The test groups were designated as follows:

- Groups 1-5—standardized core build-up
- Groups 6-10—specimens prepared for full gold crown (FGC) on standardized core build-up.
- Group 11—control (sound) teeth.

The five core build-up materials selected for the investigation, details of which are given in Table 1, were allocated at random to groups 1-5 and groups 6-10.

Specimen Preparation

Each selected tooth was mounted in a steel mold with autopolymerizing resin extending over the radicular portion of the tooth to 2 mm below the cemento-enamel junction. Mesio-occlusal-distal (MOD) preparations of standardized design were completed in the selected teeth in groups 1-10, including the removal of both lingual cusps, with the width of the remaining buccal portion of the crown of the tooth being one-third of the bucco-lingual width (BLW) of the tooth (Figure 1). This

Table 1: *Details of the Core Build-Up Materials Investigated*

Code	Material	Type	Manufacturer	BatchNumber
PR	Prisma-APH	Resin composite Shade U & LY	DeTrey, Dentsply Weybridge, UK	U: 606.70.100 LY: 0214.912
AM	Duralloy	Amalgam alloy	Degussa Ltd, Cheshire, UK	5101241/22, 5121317/12 5121316/42, 5101240/42
TC	Ti-Core	Resin composite	Essential Dental Systems, S Hackemsack, NJ, USA	Base: B042792 Catalyst: C042892
CO	Coradent	Resin composite	Vivadent, Schaan Liechtenstein	Base: 360219, 460076 Catalyst: 360218, 460407
CR	Ketac-Silver "Cermet"	Cermet Glass-ionomer cement	ESPE GmbH & CO, Seefeld/Oberbay, Germany	385/30 009A36 383/30 012A36

PR "Prisma-APH": VLC hybrid resin composite, shade U and LY.
AM "Duralloy": Silver amalgam, high copper admixed alloy (non-gamma 2) in 1, 2 and 3 spill capsules.
TC "Ti-Core": Chemically cured resin composite core material containing Titanium alloy.
CO "Coradent": Chemically cured resin composite core material containing ceramic particles.
CR "Ketac-silver": Modified, reinforced, cermet glass-ionomer cement in an encapsulated form.

was measured with the aid of Vernier calipers. The cervical margin of the preparation was placed 1 mm above the cemento-enamel junction. Conventional instrumentation and water-cooling were used throughout. The completed preparations had flat pulpal floors with no mesial or distal box forms.

Two self-threading dentin pins (Whaledent Max 021 Pins; Coltene/Whaledent Inc, Altstatten, Switzerland) of 0.525 mm diameter were placed in each preparation according to the manufacturer's instructions: a contrangle handpiece running at low speed was used. A new twist drill was used for each specimen. One pin was placed in each of the mesiolingual and distolingual pin sites 1 mm within the dentino-enamel junction (DEJ) (Figure 2). In the event any pins were found to be loose on placement or incompletely seated, the affected tooth was rejected and replaced by another of similar size.

The materials were handled and placed strictly according to the manufacturers' instructions for use, with the composite cores being bonded with Prisma Universal Bond 3 (Dentsply, Weybridge, UK), the Duralloy cores being resin bonded using Panavia 21 (Kuraray Co, Japan) and the cores of Ketac Silver being placed in preparations conditioned with 30% polyacrylic acid. No liners or bases were placed prior to the placement of the cores. All the materials were placed incrementally, initially around the dentin pins.

The gingival seat of the core build-up restorations were formed against a transparent molar matrix band (Lucifix, Hawe Neos, Switzer-land) except for the core build-ups of amalgam which were packed against a metal matrix band. The Prisma APH was placed in increments not exceeding 1.5 mm in depth and cured by 60 second exposures to light from a Luxor light curing unit (ICI Dental, Macclesfield, UK). All the core build-ups were overbuilt and contoured using water-cooled diamond burs. To eliminate the effects of differences in tooth and cuspal inclination angles described by Khers and co-workers (Khers, Carpenter, Vetter & Staley, 1990), the core build-up procedures were completed with the lingual cusps being contoured to the level of buccal cusps using preformed occlusal indices (of vinyl polysiloxane putty) to guide the contouring. Following core build-up placements, specimens from Group 1-5 were stored in tap water at room temperature (22°C) for 24 hours before testing. Group 6-10 specimens were stored in tap water at room temperature (22°C) for 24 hours before full gold crown (FGC) preparation.

The FGC preparation (Figure 3) was completed on each specimen in groups 6-10, using conventional instruments and techniques. A new bur was used for each preparation. The preparation, which included uniform occlusal reduction of 1 mm, was given a 10° taper using a specially designed bur held in a Bachmann design parallelometer. A 135° chamfer finish was prepared in tooth tissue immediately apical to the gingival margin of the core build-up restoration. Each preparation was completed with the aid of preformed indices and guides to control the extent of the preparation. The prepared specimens were stored in room temperature (22ºC) water for 24 hours prior to testing.

Fracture Testing

A universal testing machine (RDP Howden Ltd, Leamington Spa, UK) was used to load the specimens in compression at a cross-head speed of 1 mm per minute. Load was applied to the occlusal surface of the restoration by means of a 4 mm diameter steel bar placed mesio-distally and perpendicular to the long axis of the tooth. The steel bar rested on the occlusal surface making contact with the cuspal inclines (Figure 4). In the teeth prepared for FGC in groups 6-10, the steel bar contacted both the occlusal surface and marginal ridges. Force was applied until the specimen fractured, with

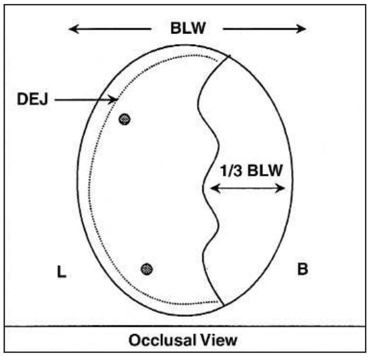

Figure 1. *Occlusal view of core build-up preparation showing position of pin holes.*

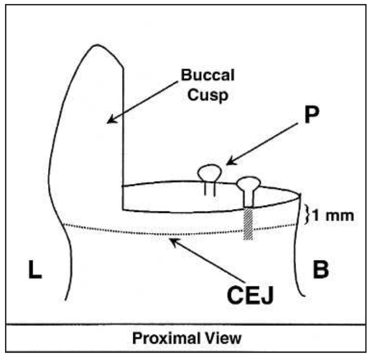

Figure 2. *Proximal view of core build-up preparations showing position of pins and relation of preparation to CEJ.*

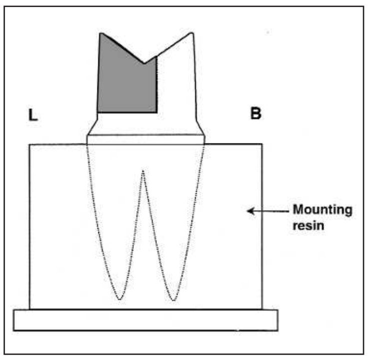

Figure 3. *Core build-ups design.*

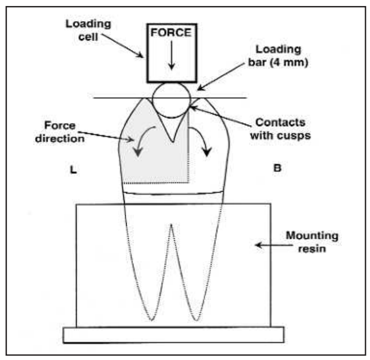

Figure 4. *Fracture test design.*

force at fracture (kN) and mode of fracture being recorded. Force at fracture data were statistically analyzed utilizing one-way and 2-way ANOVA. The force at fracture for all the materials was also compared using a student's *t*-Test.

RESULTS

The fracture load (kN) results for the core build-ups of the five materials for the matched core build-ups/FGC preparation and for the control (sound) teeth are given in Table 2. The fracture strength (kN) of the investigated core build-up materials as a percentage (%) of sound tooth fracture strength (kN) is presented in Table 3. From these results it was apparent that preparation for FGC resulted in a reduction in the fracture strength of core build-up restored teeth, irrespective of the material used.

Regarding the mode of fracture, the sound (control group) teeth, which had the highest fracture resistance of the teeth tested, tended to fracture in a way that involved clinically significant amounts of tooth tissues. In most cases (70%), the fractured tooth was left irreparably damaged, with the tooth splitting into two halves. This mode of fracture was one of five types of fracture observed:

a) Mesio-distal fracture of the tooth into two halves involving pulp and roots.

b) Mesio-distal fracture of the tooth together with fracture of the lingual cusps.

c) Fracture of the proximal sections.

d) Fracture of proximal sections together with mesio-distal fracture of the tooth.

e) Mixed fracture involving a combination of the above.

Further examination of the specimens showed that the mode of fracture was dependent on the site of contact of the steel loading bar, which in turn was dependent on the morphology of the occlusal surface of the specimen being tested. As a consequence, if the contact was on the restored marginal ridges, the fracture of the tooth tended to involve the proximal areas, whereas if the contact of the steel bar was mainly on the cusp inclines, the restored lingual cusps tended to fracture.

Fracture strength data for the core build-up of the five materials investigated were statistically analyzed utilizing 2-Way ANOVA at $p<0.050$. This revealed that highly significant differences exist between the groups ($p=0.0001$). The 2-Way ANOVA also showed interactions between the type of material used and the crown preparation procedure ($p=0.0001$) with a correlation coefficient of 0.917. Significant differences were found to exist between the core build-up and prepared core build-up groups ($p<0.05$).

Table 2: *Summary of the Results for the Fracture Strength (kN) Standard Deviation (sd) and t-Test Values of the Restored and Prepared Core Build-Ups and Control Teeth*

	Status of Teeth				
	Sound	Restored	Prepared	*t*-Test	
Material	Mean (sd)	Mean (sd)	Mean (sd)	t-Value	t-Prob
Control	3.96 (0.16)	---	---		
Amalgam	---	2.58 (0.11)	1.17 (0.08)	30.61	0.000
Prisma APH	---	2.08 (0.08)	1.70 (0.09)	8.97	0.000
Ti-Core	---	1.56 (0.11)	1.37 (0.09)	4.08	0.001
Coradent	---	1.39 (0.09)	1.13 (0.06)	6.86	0.000
Cermet	---	0.72 (0.07)	0.39 (0.08)	8.86	0.000

DISCUSSION

Core build-ups must be capable of resisting occlusal forces since they may often be required to act as semi-permanent restora-

Table 3: *Summary of Fracture Strength of Tested Core Build-Up Materials for Restored and Prepared Teeth for Full Veneer Gold Crown as a Percentage (%) of Sound Tooth (Control) Fracture Strength (kN)*

Material	Status of Teeth		
	Sound Strength (%)	Restored Strength (%)	Prepared Strength (%)
Control Teeth	100%	---	---
Amalgam	---	65%	29%
Prisma APH	---	52%	43%
Ti-Core	---	39%	34%
Coradent	---	35%	28%
Cermet	---	18%	10%

tions, for example, while the clinician assesses the success of a root filling. This study assessed the fracture strength of five materials that were considered representative of the range of materials used in the UK for core build-up procedures at the time of the study. This included a universal resin composite, a tried-and-tested non-gamma-2 amalgam, examples of resin composite materials specifically intended for core build-up procedures and a cermet, rather than a traditional glass ionomer material. Indeed, during the time subsequent to the study, glass ionomer materials of higher filler loading have been introduced, and it may be considered that their superior physical properties would make these more appropriate to core build-ups than the cermet material employed in this study. Nevertheless, cermet materials have been used extensively and continue to be used as core build-up materials, hence their inclusion in this study.

While the core build-up must be capable of resisting fracture, so, too, must the prepared core, given that it provides a foundation for the overlying crown when placed. A prepared core of low strength will ultimately lead to failure of the crown, since it will be unable to resist the forces directed through the crown onto it. It is, therefore, relevant to assess the strength of the prepared core as well as the unprepared core build-up. Indeed, if clinicians select core materials on the basis of the adequacy/strength of the core build-up with no consideration for the effects of preparation, then as the results of this study indicate, the best possible result may not be obtained. In both the pre- and post-preparation data, it is not the absolute fracture resistance values that matter, but more the ranking of the materials and the different modes of failure.

The methods used in this *in vitro* investigation were designed to as closely as possible simulate the clinical situation. However, it is acknowledged that the exact replication of fractures seen clinically is difficult. As in related studies, the use of a 4 mm steel bar, which may be easily positioned along the mesio-distal fissure of the teeth, served to replicate occlusal loading (Burke & others 1993). Nevertheless, it is suggested that the methods used in this study allow comparisons to be made between groups and may provide a potential indication to clinical outcomes. The preparation for the core build-up was also considered typical of that seen clinically, where the fracture of one or two lingual cusps following restoration of a tooth with an MOD restoration is a relatively common occurrence (Patel & Burke, 1995). In the core build-up preparation utilized, the loss of tooth substance extended approximately half way through the coronal dentin. This was considered to represent a robust but clinically appropriate test to the core material.

Using composites specifically designed for core build-up procedures (Ti-Core and Coradent) could have been expected to be superior to the hybrid restorative composite (Prisma APH) in terms of percentage fracture strength. However, as the fracture resistance of the teeth restored using Ti-Core and Coradent was found to be substantially lower than that for the teeth restored with the hybrid composite (Prisma APH) and amalgam, there appears to be no advantage in using the reinforced composite restoratives investigated, at least under the conditions of this study.

This study made no indications that showed the mode of fracture was influenced by the type of restorative material used. The mean fracture strength of sound teeth was found to be 3.96 kN ± 0.16 kN. This was significantly higher than the value for any of the restored teeth ($p<0.05$). From Table 3, the core build-up materials could be ranked according to fracture resistance of the restored tooth units as follows:

Amalgam>Prisma-APH>Ti-core>Coradent>Cermet, with percentage fracture strengths of 65%, 52%, 39%, 35% and 18%, respectively, relative to the sound tooth controls.

A general decrease in the fracture strength of the restored teeth following FGC preparation, was shown, with the ranking of the materials according to fracture resistance as follows:

Prisma-APH>Ti-core>Amalgam=Coradent>Cermet, with the percentage fracture strengths of the prepared core build-ups being 43%, 34%, 29%, 28% and 10%, respectively. It may be seen from these data that teeth restored with an amalgam core build-up suffered a substantial reduction in fracture strength following FGC preparation, with this reduction being greater than that for any of the other materials. The reductions in fracture strength for all the materials was found to be statistically significant ($p<0.05$) when a student's *t*-Test was applied. This effect may have resulted from thinning of the core build-up, notably in relation to the retentive pins and proximal sections following full gold crown preparation, or to loosening of the amalgam cores during preparation, although this was not apparent when the specimens were examined prior to testing. While it is difficult to interpret the significance of these findings with regard to the clinical situation, the data may suggest that when amalgam is clinically used as a core build-up material that steps be taken to minimize the subsequent preparation and that thinning of the core in preparation is minimized, or that as much material as possible is placed during the core build-up. Alternatively, using bonding techniques during core build-ups with amalgam will enhance the fracture resistance of the prepared core (vide supra).

In the unprepared core build-up groups, restored lingual cusps were found to be more prone to fracture than the buccal cusps of remaining tooth tissues. This finding is mirrored in the clinical situation, where the lingual cusps of lower molars tend to fracture more often than the buccal cusps (Cavel, Kelsey & Blankeman, 1985: Eakle, Maxwell and Braly, 1986). It is pertinent to note that teeth restored with each of the five core build-up materials tended to fracture in a way that did not involve clinically significant amounts of remaining tooth substance. The typical mode of fracture for the restored teeth was in a plane associated with the retentive pins and related to the point(s) of loading on the occlusal surface, generally in the slopes of both lingual cusps that had been rebuilt level with the buccal cusps. The loading force appeared to act as a shearing force to dislodge the lingual section of the restoration from the retentive pins.

Regarding the extent of the fracture, it generally took one of two forms: a fracture involving only the restored cusps, or a fracture involving the restored cusps and one or both of the proximal portions of the build-up exposing typically one or both of the retentive pins.

In some of these cases, it was noted that the retentive pins had been bent during the fracture of the core build-up, although there was no macroscopic evidence of cracking or crazing of adjacent dentin or loosening of the retentive pins.

When tooth tissues were involved in the fracture of the restored teeth, it was limited to a section of the gingival seat. However, in four cases (two Prisma-APH, one Ti-Core and one Coradent build-up) the fractures were more extensive, involving clinically significant amounts of remaining tooth tissues with or without core displacement and the displacement of one or both of the retentive pins. This supports previously reported findings (Purk, Eick & DeSchepper, 1990) in suggesting that the use of amalgam rather than composite is more desirable in cases of a high fracture risk. In amalgam restorations, only the material is likely to fracture, while in composite restoration, the remaining tooth structure is at higher risk.

A substantial proportion of the cores were fractured in such a way as to expose one or both retentive pins. This lends support to the widely held view that pins, although recognized as helpful in the retention of extensive restorations, may act as a source of weakness within the restoration. Brackett & Johnston (1989) and Burgess & Summitt (1991) have shown that retentive pins improve the retention of the restoration but increase its fracture susceptibility. Lloyd & Butchart (1990) subsequently found that retentive pins induce a fracture of the surrounding restorative material when submitted to heavy forces. This study's findings confirm those of Lloyd & Butchart (1990) and concur with Welk & Dilts (1969), who also concluded that pins weaken restorations. Furthermore, recently proposed techniques, such as amalgapins for complex amalgam restorations, may not provide adequate retention given that a recent study using four amalgam combinations on simulated dentin has demonstrated fracture of the amalgapins in all specimens tested, although the performance of a spherical alloy was superior to other amalgam types (Schulte & others, 1998).

Burgess and co-workers have recently examined the fracture resistance of complex amalgam restorations (Burgess, Alvarez & Summitt, 1997). Their results indicated that using an amalgam bonding system (Amalgambond Plus, Parkell, NY) to bond large amalgam restorations to molar teeth produced a group of specimens of similar fracture resistance to a group in which four pins were used for retention. Furthermore, when pins and the bonding system were employed, the fracture resistance of the specimens was increased by more than 100%. In the clinical situation, the satisfactory use of amalgam bonding in non-retentive or minimally-retentive preparations has been demonstrated by researchers (Burgess & co-workers, 1996; Ruzichova & co-workers, 1996; Stewart & Belcher, 1996), although these studies were only of one year and two years' duration, respectively. It would therefore appear that further work to investigate whether bonding of amalgam core build-ups actually enhances the fracture resistance of the restored tooth units is indicated.

CONCLUSIONS

Amalgam core build-ups placed according to the protocol of this study demonstrated higher fracture resistance than the other composite and cement materials examined. But when the cores were reduced during standardized crown preparations, the reduction in fracture resistance was greatest with the amalgam specimens. Prepared core build-ups involving a hybrid composite material provided the highest fracture resistance. The cermet material used provided the lowest resistance to fracture in both the core build-up and crown preparation specimens. No advantage was apparent, in terms of fracture resistance, in using the composite materials included in this study, which are specifically marketed as core build-up materials.

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Effect of Collagen Removal on Shear Bond Strength of Two Single-Bottle Adhesive Systems

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Clinical Relevance

Using sodium hypochlorite to remove collagen may enhance bond strength between resin and dentin when an acetone-based adhesive system is used.

SUMMARY

This study evaluated the effect of collagen removal on the shear bond strength for two single-bottle adhesive systems. The ultrastructure of the dentin after treatments and the dentin-resin interface were examined under SEM. The buccal and lingual surfaces of 80 extracted human third molars were ground to expose dentin. Teeth were randomly assigned to four groups and received the following treatments: Group 1(P&B 2.1), Prime & Bond 2.1 adhesive was applied according to the manufacturer's directions and Restorative Z100 composite resin was bonded to the dentin surface; Group 2 (P&B 2.1/NaOCl), the same procedures were followed as for Group 1 except that the surfaces were treated with 10% sodium hypochlorite (NaOCl) for one minute after acid conditioning; Group 3 (SB), Single Bond (3M) was applied according to the manufacturer's recommendations; Group 4 (SB/NaOCl), the same procedure was followed for Group 2, using Single Bond. The specimens were stored in humidity at 37°C for 24 hours and tested in a shear mode at a crosshead speed of 0.5 mm/minute. The Kruskal-Wallis test and Multiple Comparisons were used for statistical analysis of the data. A one-minute exposure of dentin to 10% NaOCl following acid conditioning resulted in a significant increase of the dentin shear bond strength for Prime & Bond 2.1. The same treatment for Single Bond resulted in a significant reduction in bond strength. Groups 1 and 3 were not statistically different from each other. The presence of a collagen layer resulted in the formation of a hybrid layer and similar values of adhesion for both adhesive systems. The results may suggest that collagen removal improves the bond strength for this acetone-based adhesive system but several such systems would need to be investigated.

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INTRODUCTION

Resin penetration into dentin with monomer impregnation of the exposed collagen resulting in formation of hybrid layer is widely accepted as an efficient method to improve resin composite bond strength to dentin (Nakabayashi, Kojima & Masuhara, 1982;

Nakabayashi, Ashizawa & Nakamura, 1992; Gwinnett, 1994; Sano & others, 1995; Pashley & Carvalho, 1997). However, scanning electron microscopy (SEM) examination of test specimens fractured under tensile stress has suggested that deterioration of adhesion and the resultant decrease in bond strength after long-term water immersion occurs in a band of exposed collagen that has not been impregnated with resin (Nakabayashi & others, 1992). This phenomenon may be due to the low permeability of dentin resulting in non-efficient penetration of adhesive into this substrate (Nakabayashi & others, 1992).

Dissolution of collagen after acid conditioning may result in better resin diffusion by increasing dentin permeability and changing its composition, leaving it with a layer of mineral exposed on its surface (Vargas, Cobb & Armstrong, 1997). More predictable adhesion could be obtained directly with hydroxylapatite of partially demineralized dentin by removing the collagen (Vargas & others, 1997).

Recent studies have showed that the layer of collagen does not offer a direct quantitative contribution to the interfacial bond strength (Gwinnett, 1994; Uno & Finger, 1995; Fujita & others, 1996; Vargas & others, 1997; Chersoni & others,1998), which is probably due to a complete resin diffusion into the porous, partially-demineralized dentin (Gwinnett, 1994; Uno & Finger, 1995; Gwinnett & others, 1996; Vargas & others, 1997), and the collagen layer may not be crucial to the mechanism of adhesion between resin and dentin (Vargas & others, 1997).

Dissolution and removal of the organic collagen layer after acid conditioning and subsequent bonding directly to the partially-demineralized dentin layer may produce more durable adhesion to the hydroxylapatite component of the dentin substrate. Moreover, absence of a non-encapsuled collagen band at the dentin-resin interface could prevent degradation of this interface after storage in water for extended periods (Nakabayashi & others, 1992).

This study (1) evaluated the effect of a one-minute exposure of 10% sodium hypochlorite (NaOCl) following acid conditioning of the dentin on the shear bond strength of two single bottle adhesive systems: an acetone-based (Prime & Bond 2.1) and an ethanol/water-based (Single Bond), and (2) examined the ultrastructure of the resin-dentin interface using SEM.

Table 1: *Adhesive Systems Used in This Study*

Prime & Bond 2.1	UDMA, PENTA, R5-62-1 resin, BPDM Butylated hydroxytoluene, 4-ethyl dimethyl aminobenzoate, cetylamine hydrofluoride, acetone, PI
Single Bond	HEMA, Bis-GMA, dimethacrylates, methacrylates pendant polyalkenoic acid copolymer, ethanol, water, PI

UDMA: urethane di-methacrylate; PENTA: phosphoric penta-acrylate ester; PI: photoinitiator; BPDM: bisphenol di-methacrylate; Bis-GMA: bisphenol-glycidyl methacrylate; HEMA: 2-hydroxyetyl methacrylate

METHODS AND MATERIALS

Shear Bond Strength Test

Forty recently extracted, sound human third molars stored in a solution of 10% formalin (pH 7.0) and two recent one-bottle dentin adhesive systems were used in this study (Table 1). Teeth were cleaned with scalers and flour pumice and stored in distilled water for one week before the study. After sectioning from the roots 1 mm under the cementoenamel junction, the crowns were sectioned in a mesio-distal direction. Eighty fragments obtained were embedded in polyester resin, and flat peripheral dentinal areas were exposed on the lingual or buccal surfaces by wet grinding on aluminum-oxide abrasive paper, grits 320, 400 and 600, using a copious water supply directed onto the rotating platen of a polishing machine. The dentin area to adhesion was defined by applying fenestrated PVC film on the dentin surface. The PVC film had a circular hole in its center 3 millimeters (mm) in diameter. The fragments were randomly assigned to four groups of 20 each and received the following treatments.

GROUP 1 (P&B 2.1)–Prime & Bond 2.1 (Dentsply Ltda, RJ 90915, Brazil). Dentin surfaces were conditioned with 36% phosphoric acid (H_3PO_4) gel (Dentsply Ltda, Petrópolis, RJ 90915, Brazil) for 15 seconds, rinsed with water for 15 seconds and blot-dried leaving a moist surface. Prime & Bond 2.1 was applied according to the manufacturer's directions and light cured with an Optilux 500 (Demetron Ressearch Corp, Danbury, CT 06810) visible light-activation unit. The light output, measured with a curing radiometer was 650 mW/cm_2. The mounted fragments were positioned in the assembly apparatus. The split teflon mold with a circular hole, 3 mm in diameter and 5 mm deep, was locked in the assembly apparatus. The finger spring was released to elevate the platform and compress the dentin surface of the embedded tooth firmly against the base of the split teflon mold. Z100 composite resin (3M Dental Products, St Paul, MN 55144), shade C3, was transferred to the opening in the split teflon mold in two increments, and each increment was compressed firmly and light cured for 40 seconds. The specimens were then removed from the assembly apparatus, the split teflon mold and PVC film were removed and an additional 40 seconds of light curing was done.

GROUP 2 (P&B 2.1/NaOCl)–Prime & Bond 2.1 + NaOCl. The same procedures were followed as in Group 1, but a solution of 10% NaOCl was applied for one minute after acid conditioning, then rinsed for 30 seconds and blot-dried before applying the adhesive.

GROUP 3 (SB)– Single Bond (3M Dental Products, St Paul, MN 55144). Dentin surfaces were conditioned with 36% H_3PO_4 gel for 15 seconds, rinsed with water for 15 seconds and blot-dried, leaving a moist surface. Single Bond adhesive was applied and light cured following manufacturer's instructions. The composite resin application and its light cure were done as in Group 1.

GROUP 4 (SB/NaOCl)–Single Bond + NaOCl. The same procedures were followed for Group 3 except that a solution of 10% sodium hypochlorite was applied after acid conditioning, then rinsed for 30 seconds and blot-dried before applying the adhesive.

The specimens were immersed in distilled water and stored for 24 hours at 37°C and shear bond strength was measured in a Emic Universal Test Machine (Emic DL-500, SJ Pinhais, PR, 83020 Brazil). A parallel knife-edge shearing device was aligned 0.05 mm from the bonded interface and force was applied to failure using a crosshead speed of 0.5 mm/min. The Kruskal-Wallis test and Multiple Comparisons were used for statistical analysis of the data.

Table 2: *Exploratory Measures (median, average and variance) and Kruskal-Wallis Test Results*

Group	n	Median	average	variance	sum of ranks
1-P&B 2.1	15	15,02	17,59	39,20	481,5 b
2-P&B 2.1/NaOCl	19	21,84	21,83	42,37	857,5 a
3-SB	17	15,99	15,85	18,48	484,0 b
4-SB/NaOCl	15	13,82	15,32	21,66	388,0 c

*different letters means statistical differences and vice-versa
LSD(15,15) = 18,23 LSD(15,17) = 17,68
LSD(15,19) = 17,24 LSD(19,17) = 16,66

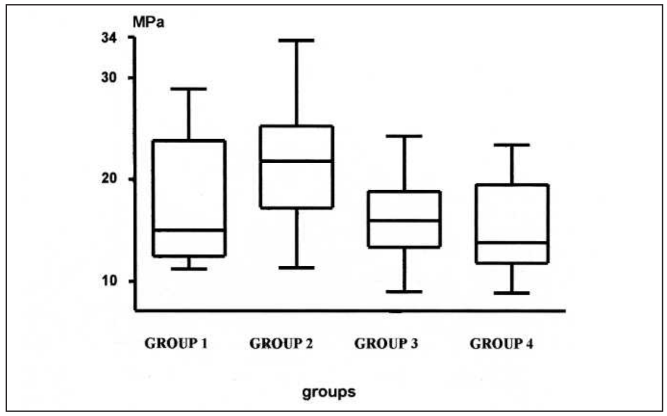

Figure 1. *Box-Plot diagram to illustrate the results.*

SEM Evaluation

Dentin Surface After Treatments

To examine the effects on dentin from treatments employed in this study, four dentin disks 2 mm thick were obtained by parallel sectioning of the crown portion of freshly extracted human third-molar teeth. The exposed dentin of two disks was treated with 36% phosphoric acid for 15 seconds and rinsed with water for 15 seconds. The other dentin disks received the same treatment and subsequent application of 10% sodium hypochlorite for one minute and rinsed with water for 30 seconds. Immediately after these treatments, specimens were immersed in Karnovisk-modified solution, then dehydrated in acetone. The dehydrated specimens were transferred directly from the acetone dehydrating solution to the critical-point drying apparatus (CPD 030 Balzers, Oberkochen, 73446 Germany).

Eight dentin disks 2 mm thick were obtained using the same procedure, and pairs of dentin disks were prepared according to the four dentin treatments used for the shear bond strength portion of the study. The treated surfaces of each pair were then bonded together with Z100 restorative composite resin. Specimens were stored in distilled for 24 hours at 37°C. Each disk was sectioned perpendicular to the bonded interface using a diamond disk (KG Sorensen Ind & Com, Alphaville, São Paulo, SP 06454920, Brazil) mounted in a low-speed handpiece under copiously water lavage. To prepare the specimens for observation in SEM, the sectioned segments were wet-abraded using a sequence of 600, 800 and 1000 grit wet/dry abrasive paper (Norton Abrasivos SA, São Paulo, SP,07844120 Brazil) on a flat surface. The specimens were cleaned of adherent abrasive particles between each change of abrasive by immersion in distilled water for three minutes of ultrasonication followed by copious rinsing. In order to remove all adherent abrasive particles, the specimens were copiously rinsed with distilled water while being rubbed with a cotton swab, then immersed for 30 minutes in an ultrasonic bath of distilled water. The flat, polished surface was treated with 6 mole/L hydrochloric acid for 30 seconds and rinsed with distilled water. The specimens were then immersed in 1% sodium hypochlorite for 10 minutes, after which they were copiously rinsed with distilled water. This procedure dissolved a small amount of tooth structure away from the tubular resin tags, leaving them standing in relief above the remaining tooth structure. These specimens were dried in an oven at 37°C for three hours.

All specimens were then sputter coated (MED-010 Balzers, Oberkochen, 73466 Germany) and examined in a SEM (ZEISS DSM-940 A, Oberkochen, 73466 Germany).

RESULTS

The Kruskal-Wallis test showed significant differences between the groups (H=10.59; α=0.0141) and the

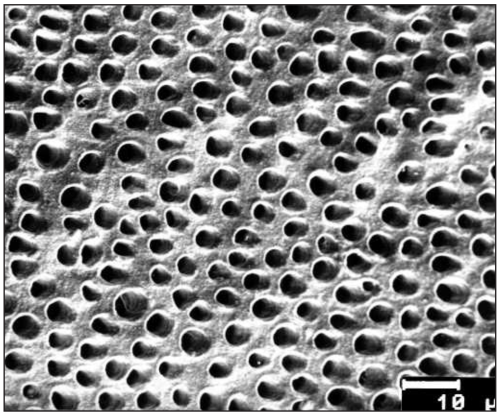

Figure 2. *Dentin surface treated with 36% H_3PO_4 for 15 seconds. The etching removed the smear layer and opened the tubules (x1000).*

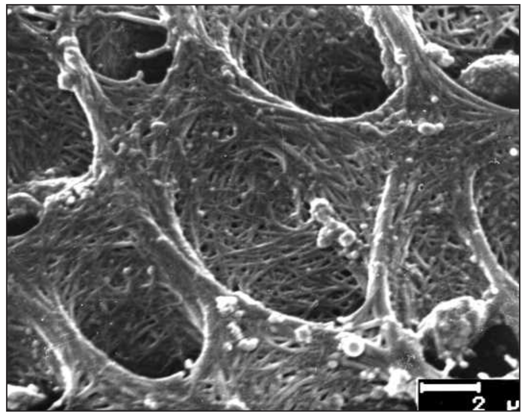

Figure 3. *Following conditioning with 36% H_3PO_4, the collagen network of intertubular dentin is evident (specimen was dried at the critical point) (x5000).*

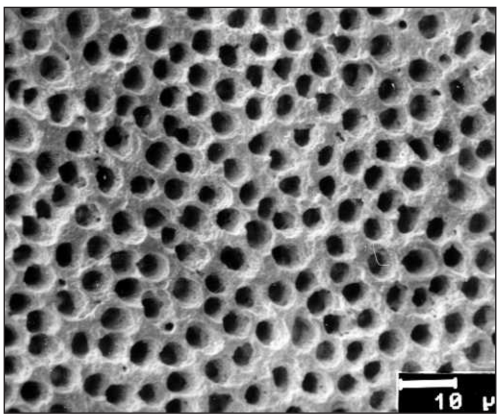

Figure 4. *Dentin surface treated with H_3PO_4 for 15 seconds followed by 10% NaOCl for 60 seconds. The collagen network was removed by NaOCl treatment. Compared with etching, the tubules are wider with less intertubular dentin superficially (x1000).*

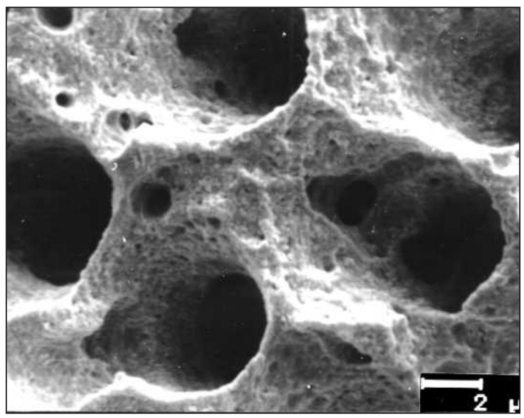

Figure 5. *Surface treated with NaOCl after etching with H_3PO_4. Intertubular dentin is porous and rough (x5000).*

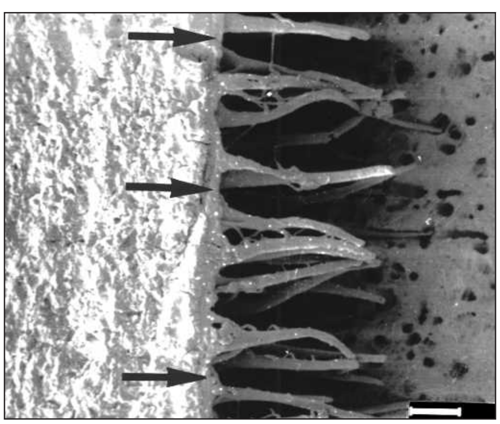

Figure 6. *Cross-section of interface between Prime & Bond 2.1 and 36% H_3PO_4 treated dentin. The dentin was removed by HCl and NaOCl. A distinct hybrid zone (arrows) is evident with penetration of resin tags into dentin tubules (x1000).*

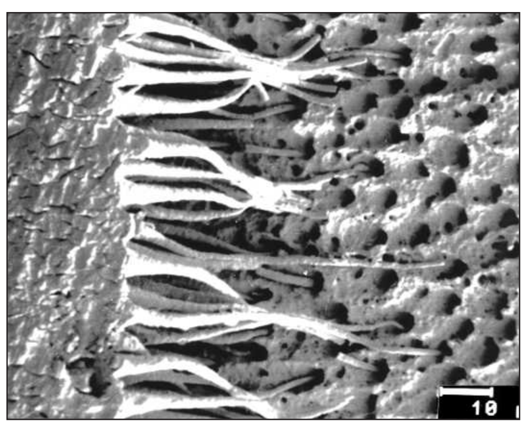

Figure 7. *Cross section of interface between Prime & Bond 2.1 and dentin substrate treated with 36% H_3PO_4 and NaOCl. The dentin was removed by HCl and NaOCl, clearly revealing penetration of resin tags into the dentin tubules and tubular anastomoses. No hybrid zone is evident (x1000).*

results of the Multiple Comparison Test are shown in the Table 2 and Figure 1.

Group 2 (P&B 2.1/NaOCl) showed the highest value for SBS, which was statistically different from the other groups. No significant differences were noted between Groups 1 (P&B 2.1) and 3 (SB) that showed lower values than Group 1. Group 4 (SB/NaOCl) revealed the lowest values of shear bond strength ($p<0.05$).

The dentin conditioning with 36% phosphoric acid for 15 seconds opened dentin tubules and left a high amount of collagen under the surface of partially-demineralized dentin (Figures 2 and 3). This treatment, followed by a 10% sodium hypochlorite application for one minute, removed the collagen network, leaving the intertubular dentin surface more irregular and produced comparable topographical features with funnel-shaped dentin tubules (Figures 4 and 5).

Figures 6 and 8 show typical features of dentin hybridization. A narrow zone of intertubular resin infiltration and accompanying resin penetration into the dentin tubules were present, common to both adhesive systems, when only the treatment with 36% phosphoric acid was used. In specimens treated with 10% sodium hypochlorite, no zone of hybridization was observed although tubules and their lateral branches were completely filled with resin (Figures 7 and 9).

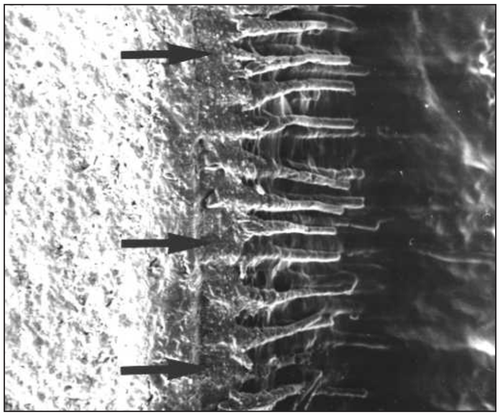

Figure 8. *Cross-section of interface between Single Bond and 36% H_3PO_4 treated dentin. The dentin was removed by HCl and NaOCl. A distinct hybrid zone (arrows) is evident with penetration of resin tags into the tubules (x1000).*

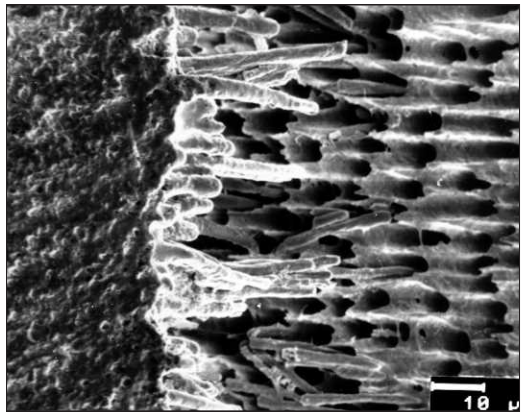

Figure 9. *Cross-section between Single Bond and dentin substrate treated with 36% H_3PO_4 and NaOCl. The dentin was removed by HCl and NaOCl clearly revealing penetration of resin tags into the tubules. No hybrid zone is evident (x1000).*

DISCUSSION

It is clinically very important to enhance the adhesion between dentin and adhesive resin because such improved adhesive strength not only leads to better retention of restorations but also prevents marginal leakage, thus reducing the chance of developing secondary caries (Wakabayashi & others, 1994).

It is widely accepted that bonding to dentin relies on the penetration of adhesives into the collagen fibers and encapsulation of the irregular hydroxylapatite crystals at the bottom of the decalcified area, which create the resin-reinforced interdiffusion zone called hybrid layer (Nakabayashi & others, 1982; Nakabayashi & others, 1992; Gwinnett, 1994; Sano & others, 1995) (Figure 6). However, it is difficult to diffuse adhesive resin onto the collagen layer to reach the adherent surface (Ciucchi, Sano & Pashley, 1994; Wakabayashi & others, 1994;) and failure of adhesive penetration may leave collagen fibers unprotected and exposed to oral environment (Vargas & others, 1997). These unprotected fibers may be submitted to hydrolysis after long-term exposure to water, leading to deterioration of adhesion between resin and dentin, resulting in decreased bond strength (Nakabayashi & others, 1992). Nanoleakage in the hybrid layer was mentioned by Sano & others (1995) as one factor which affected degradation of dentin bonding. Wakabayashi & others (1994) indicated that bond strengths after long-term water immersion were significantly higher for those specimens where the collagen was removed after acid conditioning, suggesting that degradation of the bond was due to the hydrolysis of unprotected collagen fibers.

In the combined phosphoric acid and sodium hypochlorite treatment technique used herein, the dentin surface was first decalcified to expose the collagen (Figure 3). The exposed collagen was then dissolved with NaOCl (Figure 5), and adhesive resin was directly applied to the dentinal apatite exposed on the dentin surface as first described by Uno & Finger (1995).

The hypothesis verified on this work was that collagen removal would result in increased dentin permeability and the adhesive could penetrate more into the substrate, resulting in a more homogeneous adhesive interface of uniform thickness. In this way, the whole band of demineralized and deproteinized dentin would be impregnated by adhesive.

The positive effect of NaOCl on the bond strength of acetone-based adhesive can be explained by the higher diffusibility of the acetone as well as its higher capacity to displace water (Jacobsen & Soderholm, 1995). These factors could improve the contact of the monomer with the irregular intertubular dentin structure exposed by NaOCl treatment (Figures 4 and 5). Furthermore, removing collagen could improve the contact of adhesive and hydroxylapatite crystals by enhancing dentin permeability.

Even though the two materials have different capacities for displacing water and diffusing into the substrate, when collagen was left intact, this diffusion was enough to promote an attachment with the collagen network, resulting in similar values of adhesion for both adhesive systems (Table 2). It was concluded that in the presence of collagen, acetone or ethanol/water-based adhesive systems form a hybrid layer that results in equivalent values of adhesion for these materials.

According to the manufacturer's instruction, the ethanol/water-based adhesive system (Single Bond) was applied twice with a five-second interval in-between. As this kind of adhesive system diffuses more slowly than acetone-based systems (Kanca, 1992; Jacobsen & Soderholm, 1995), this short dwell time is insufficient to permit a full diffusion of the monomer into the substrate. In this way, nanometric porosities of intertubular dentin, created by NaOCl treatment, were not reached by monomer, leaving an adhesive interface with voids. This may explain the lowest values obtained by Group 4 (SB/NaOCl).

This study agrees with the conclusions of Vargas & others (1997) that removing the collagen layer may be beneficial for resin-to-dentin bonding in some adhesive systems but not in others, although the time between the applications of ethanol/water-based adhesive system may have decreased the values of adhesion of this material. We hypothesize that by increasing the time between the applications of the ethanol/water-based adhesive, complete penetration into the substrate would occur, resulting in values of adhesion identical to the ones obtained with the acetone-based adhesive system.

Inai & others (1998) found similar results to those obtained in this study with regard to acetone-based and ethanol/water-based adhesive systems. They hypothesized that the observed roughness of the surfaces treated with NaOCl may contribute to the increase of the shear bond strength because of their mechanical retention. Considering the monomer components, Prime & Bond 2.1 contains a phosphoric acid ester. It is possible that these phosphate terminals may have some kind of interaction with the calcium ions left on the dentin surface after collagen removal because the bond strength obtained by using H_3PO_4 and NaOCl were significantly improved for the material containing phosphoric acid ester compared to One-Step (Inai & others, 1998).

Under SEM observations, the formation of a hybrid layer was only possible when the collagen network was left intact (Figures 6 and 8). When it was removed, however, no hybrid layer was observed (Figures 7 and 9). This agrees with other recent works using SEM and transmission electron microscopy (TEM) (Gwinnett, 1994; Perdigão & Swift, 1994; Gwinnett & others, 1996; Patierno & others, 1996; Vargas & others, 1997; Inai & others, 1998).

CONCLUSION

According to the results shown in this work, collagen removal may be important when using an acetone-based adhesive system. However, additional *in vivo* and *in vitro* tests, such as leakage tests after sample fatiguing, and clinical trials are desirable in order to elucidate the effectiveness of this dentin treatment.

Acknowledgments

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Influence of Dentin Conditioning and Contamination on the Marginal Integrity of Sandwich Class II Restorations

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K-D Wernecke • J-F Roulet

Clinical Relevance

Sandwich Class II restorations show better marginal integrity than composite restorations and might be less sensitive to saliva/blood contamination.

SUMMARY

This study investigated the influence of dentin conditioning and contamination on the marginal adaptation of Class II sandwich restorations.

Large butt-joint MOD cavities with cervical margins located 1 mm below the CEJ were cut into 72 extracted human molars. Nine groups were filled using a total-bond technique with Z100 or a sandwich technique with either Vitremer or F2000 in combination with Z100. For all three material combinations three different pretreatments were compared: total etch, selective etch and dentin contamination with saliva and blood prior to primer/adhesive application. After water storage for 21 days and thermocycling (2000x, 5 - 55°C) replicas were produced for quantitative marginal analysis in the SEM. Teeth were immersed in 0.5% basic fuchsin for 24 hours and dried. Percent dye penetration over the total marginal length was analyzed in three layers using a sequential grinding techique. Statistical analysis was performed using a two-way ANOVA. Post-hoc analyses were carried out with univariate Mann-Whitney-U-tests adjusting for multiple comparisons by a sequentially rejective test procedure (Bonferroni-Holm) at $p<0.05$.

Both F2000 and Vitremer sandwich restorations showed better marginal adaptation than Z100 total-bond restorations with all pretreatments. Acid etching of the dentin significantly influenced the marginal adaptation of Z100 total-bond restorations and Vitremer sandwich restorations. All types of restorations showed considerable microleakage. On contaminated

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dentin, sandwich restorations showed better marginal integrity than total-bond restorations. Marginal adaptation did not correspond with microleakage in all groups.

In conclusion, F2000/Z100 and Vitremer/Z100 sandwich restorations show better marginal adaptation than Z100 total-bond restorations in large Class II cavities with cervical margins in dentin. Microleakage cannot predictably be prevented with the sandwich technique. Sandwich restorations seem to be less sensitive to contamination with saliva and blood.

INTRODUCTION

Despite the constant improvement of dentin bonding agents, direct Class II composite restorations show considerable leakage (Dietschi & others, 1995; Hilton, Schwartz & Ferracane, 1997; Dietrich & others, 1998) and poor marginal adaptation (Dietschi & others, 1995; Dietrich & others, 1999) in laboratory studies when cervical margins are located in dentin and are, therefore, considered contraindicated in such cavities. The "open sandwich" technique using glass-ionomer cements has been proposed to improve the marginal integrity of direct composite Class II restorations with cervical margins in dentin. This concept failed clinically when conventional glass-ionomer cements were used, mainly because of continuous loss of material (Welbury & Murray, 1990; Van Dijken, 1994). More recently, resin-modified glass ionomers have been shown to improve the marginal seal and adaptation of direct Class II restorations when used in a sandwich technique, compared to base or total-bond composite restorations (Krejci, Petrac & Lutz, 1996; Friedl & others, 1997; Dietrich & others, 1998; Dietrich & others, 1999). Using compomer materials for sandwich restorations has only recently been investigated and similar results were obtained compared to resin-modified glass ionomers (Dietrich & others, 1999). Whether resin-modified glass ionomers or compomers should be used for such restorations is difficult to decide, for different factors have to be considered when selecting a material for sandwich restorations.

To simplify the restorative procedure and ensure proper acid-etching of enamel margins, we previously proposed to acid-etch all enamel margins prior to the application of the primer of the resin-modified glass ionomer Vitremer (Dietrich & others, 1999). However, due to access difficulties and the thixotropy of the conditioners, an accidental acid-etch of at least part of the dentin might occur clinically in a posterior Class II cavity. The effect of this pretreatment on the marginal adaptation of Vitremer resin-modified glass ionomer is uncertain. The only available data concerning this problem are from bond strength measurements and the results are in part contradictory (Glasspoole & Erickson, 1995; Erickson & Glasspoole, 1998). Many compomers can be used with the same total-etch adhesive systems as the composite resins, thus making the sandwich technique less complicated. These factors argue in favor of using compomers for posterior sandwich restorations. However, some reports indicate that bonding of resin-modified glass ionomers might be less sensitive to saliva and/or blood contamination, a problem that is more likely to occur in a situation where cervical

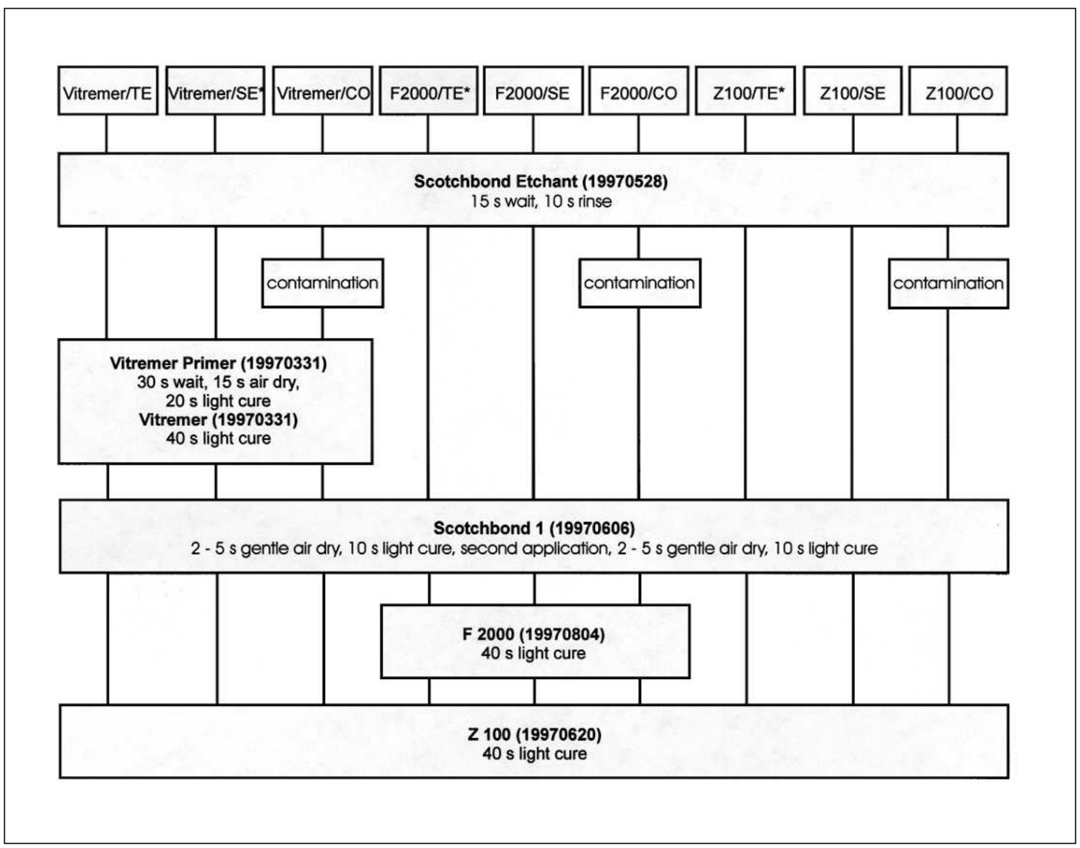

Figure 1. *Overview of experimental groups and bonding procedures, batch numbers in brackets, (*) indicates manufacturers' instruction.*

margins extend more apically (Feilzer & others, 1997; Momoi & others, 1997). Furthermore, promising clinical results have been reported for the combination Vitremer/Z100 (Burgess & others, 1998; Van Dijken & others, 1998). While these factors seem to favor using resin-modified glass ionomers, their relative importance for marginal adaptation and microleakage is unclear.

This laboratory study evaluated the influence of contamination of the cervical dentin with saliva and blood on the marginal adaptation and microleakage of sandwich restorations with either a resin-modified glass ionomer (Vitremer/Z100) or a compomer (F2000/Z100) compared to total-bond composite restorations (Z100). The effect of a total-etch on the marginal adaptation and microleakage of Vitremer/Z100 sandwich restorations was also evaluated. For F 2000/Z100 sandwich restorations and Z100 composite restorations, the effect of a selective enamel etch was also tested for comparative purposes. Finally, the influence of the material combination for a given dentin pretreatment was also evaluated.

METHODS AND MATERIALS

Sample Preparation

Seventy-two extracted caries-free human molars stored in 20% alcohol were selected. The teeth were cleaned and polished using scalers and pumice. Butt-joint MOD cavity preparations were cut using cylindrical diamond burs in a high-speed handpiece with copious water cooling. Cervical margins were placed at approximately 1 mm below the CEJ. The cavities were finished with fine grit diamonds (40 µm particle size, Komet, 32657 Lemgo, Germany). To simulate clinical conditions during restoration placement, the teeth were adapted to a model with two neighboring teeth using a silicon impression material (Silaplast, Detax, 76275 Ettlingen, Germany).

The teeth were randomly assigned to nine experimental groups (n=8, 16 proximal boxes) and restored with either sandwich or total-bond composite restorations. All restorations were made by the same operator (MK). All materials were made by the same manufacturer (3M, St Paul, MN 55144). For each material combination, three different pretreatment procedures were utilized: total-etch technique (TE), selective etch of enamel margins and dentin of the occlusal floor only (SE), contamination of cervical dentin with saliva and blood (CO).

Restorative Procedure

With the exception of the different pretreatment procedures of the dentin, all materials were applied according to the manufacturers' instructions as shown in Figure 1.

At first, all enamel margins and the dentin of the occlusal floor were acid etched. In groups Vitremer/TE, F2000/TE and Z100/TE, the cervical dentin was also acid-etched. In case of an unintentional acid etch of the cervical dentin in the groups to be selectively etched, the specimen was excluded and replaced. Teeth to be contaminated were otherwise pretreated according to the manufacturers' instructions, thus in groups F2000/CO and Z100/CO, the cervical dentin was also acid etched. In groups Vitremer/CO, F2000/CO and Z100/CO, the teeth were contaminated with fresh unstimulated human saliva for five seconds, gently air dried, contaminated with fresh capillary blood from the fingertip for another five seconds and gently air dried again. Afterwards, metal matrix bands were placed and adapted using wooden wedges. For Vitremer/Z100 sandwich restorations, Vitremer Primer was applied to the proximal boxes that were then filled to the occlusal floor with Vitremer. This was followed by the application of Scotchbond 1. In all other groups, Scotchbond 1 was applied to all cavity surfaces and the proximal boxes were filled with two horizontal layers of F2000 (F2000/Z100 sandwich restorations) or Z100 (Z100 total-bond restorations), respectively (Figure 2). In all groups, the remaining cavity was filled with two oblique layers of Z100 (Figure 2). All light curing was performed from an occlusal direction with a conventional unit (Translux CL, Heraeus Kulzer, 61273 Wehrheim, Germany). After applying the restorative material, the teeth were removed from the models to allow finishing and polishing under direct vision and optimal access with fine grade diamond burs (Composhape, Intensiv, Lugano, Switzerland) and aluminiumoxide-coated discs (Sof-Lex M,F,SF, 3M, St Paul, MN 55144).

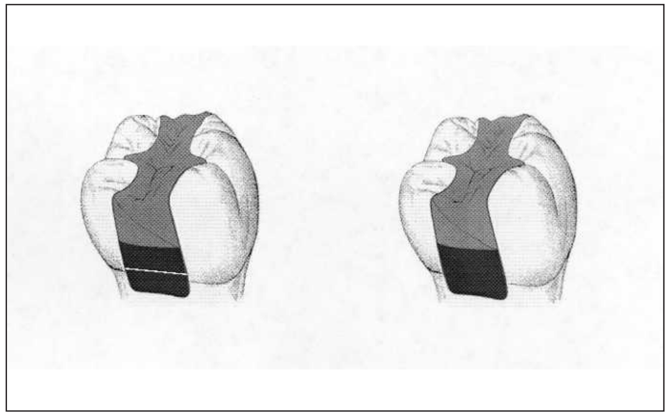

Figure 2. *Illustration of the layering technique for Z 100 total-bond restorations and F2000 sandwich restorations (left, first two increments dark) and Vitremer sandwich restorations (right, first increment dark).*

Assessment Procedure

After water storage for 21 days, the teeth were subjected to thermocycling (2000 cycles, 5-55°C). Thereafter, the teeth were cleaned and impressions taken using a polyether impression material (Permadyne, ESPE, 82229 Seefeld, Germany). Replicas were produced by casting the impressions with an epoxy resin (Stycast 1266, Emerson&Cumming, 2260 Westerlo-Oevel, Belgium). The replicas were gold sputtered (SCD 030, Balzers Union, FL-9496 Balzers, Liechtenstein), and the morphology of the cervical dentin/restoration margins was evaluated under SEM (Amray 1810, Amray, Bedford, MA 01730) using an image-analyzing software (Win-Mes V 2.03, S Küppers, 91056 Erlangen, Germany). Margins were qualitatively analyzed using the following criteria: excellent margin (smooth transition from restoration to dentin, no distinct interface visible, no gaps), marginal irregularity (uneven transition from restoration to dentin but no gap detectable), marginal opening and overhang. For quantitative marginal analysis, the percentage of margins which presented such qualities compared to the total length of the margin was calculated (Roulet & others, 1989). The sections of margins with overhangs were excluded from the quantitative analysis (Dietrich & others, 1999).

For evaluation of microleakage, the apical foramina of the teeth were sealed with wax and the surrounding tooth surface covered with nail varnish up to 1 mm from the tooth/restoration interface. Afterwards, the teeth were immersed in 0.5% basic fuchsin for 24 hours. After drying, the superficial layer of dye was removed using aluminiumoxide-coated discs (Sof-Lex, 3M, St Paul, MN 55144). Afterwards, photomicrographs of the proximal tooth/restoration surface were taken using a light microscope (6x magnification) and a digital camera. Then a total of nine 0.3 mm deep grooves were cut into the approximal surfaces along the restoration margins with a bur (#834, Komet, 32657 Lemgo, Germany) and a layer of tooth/restoration substance was removed up to the depth of the grooves with a bur (#H79E, Komet, 32657 Lemgo, Germany). Photomicrographs were taken again, followed by the removal of another 0.3 mm thick layer. Thus, photomicrographs of three layers (0 mm, 0.3 mm and 0.6 mm depth) were available for the evaluation of microleakage. Dye penetration was then qualitatively assessed (penetration or no penetration) and quantitatively analyzed as percentage of penetration over the total margin length for each layer using the same image-analyzing software as for marginal analysis in the SEM. All assessments were made by the same blinded investigator (MK).

Data were statistically analyzed using a two-way ANOVA to test for main effects and interactions of material combinations and dentin pretreatments. Comparisons were made between different material combinations for each pretreatment procedure and between different dentin pretreatments for each material combination using the univariate Mann-Whitney-U-test at $p<0.05$. Adjustments for multiple comparisons were carried out using a sequentially rejective test procedure according to Holm (Holm, 1979).

Table 1: *P-Values Obtained with Two-Way ANOVA for Excellent Margins (EM), Marginal Openings (MO) and Dye Penetration in the First (DP-1), Second (DP-2) and Third (DP-3) Layer*

variable	main effects: material	main effects: pretreatment	interaction	model
EM	< 0.001	< 0.001	0.003	< 0.001
MO	< 0.001	< 0.001	< 0.001	< 0.001
DP-1	0.001	0.07	0.027	< 0.001
DP-2	0.002	0.003	0.036	< 0.001
DP-3	0.002	0.043	0.005	< 0.001

RESULTS

The results of the two-way ANOVA are given in Table 1. The model was significant for all included effects. The different material combinations and pretreatments (main effects) significantly influenced all dependent variables with one exception (effect of pretreatment on microleakage in the first layer with $p=0.07$) and showed significant interactions.

Marginal Adaptation

The results for excellent margins and marginal openings are given in Figure 3 and Figure 4 and in Table 2. Few excellent margins were detected in Z100 total-bond restorations. Sandwich restorations with either F2000 or Vitremer showed higher percentages of excellent margins (Figure 3) and lower percentages of marginal openings (Figure 4) compared to Z100 total-bond restorations for all pretreatment procedures. These differences were statistically significant for etched and non-etched dentin. However, on contaminated dentin only Vitremer sandwich restorations showed significantly better marginal adaptation than Z100 total-bond restorations.

In Z100 total-bond restorations, significantly higher percentages of marginal openings were detected when the cervical dentin was acid etched or contaminated compared to non-etched dentin (Figure 4). The contamination of the dentin with saliva and blood did not significantly influence the marginal adaptation of Z100 total-bond restorations. The marginal adaptation of F2000 sandwich restorations was not significantly influenced by the acid etching of the dentin. However, contamination with saliva and blood resulted in significantly higher percentages of marginal openings for this type of restoration (Figure 4). The highest percentage of excellent margins was observed with Vitremer sandwich restorations when the cervical dentin was not acid etched prior to the application of the Vitremer Primer. Both acid etching and contamination of the dentin resulted in significantly lower per-

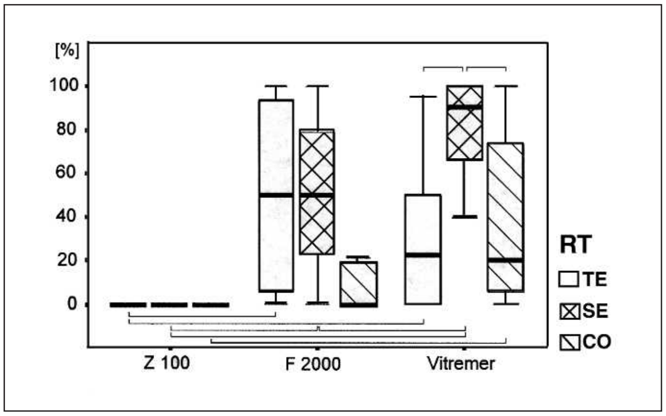

Figure 3. *Box-whisker-plots of percentages of excellent margins, brackets on top indicate significant differences between dentin pretreatments, brackets on bottom indicate significant differences between restorative techniques (*p*<0.05).*

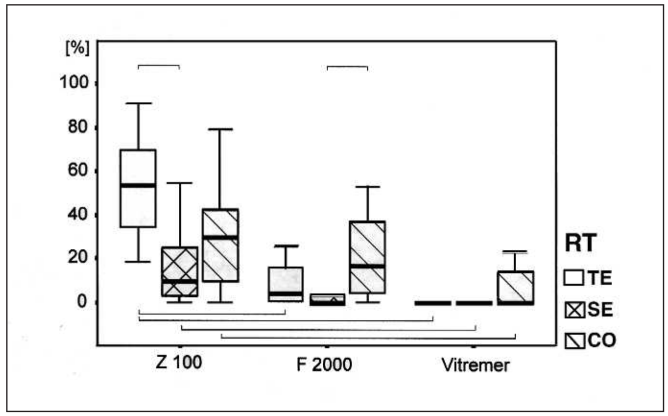

Figure 4. *Box-whisker-plots of percentages of marginal openings, brackets on top indicate significant differences between dentin pretreatments, brackets on bottom indicate significant differences between restorative techniques (*p*<0.05).*

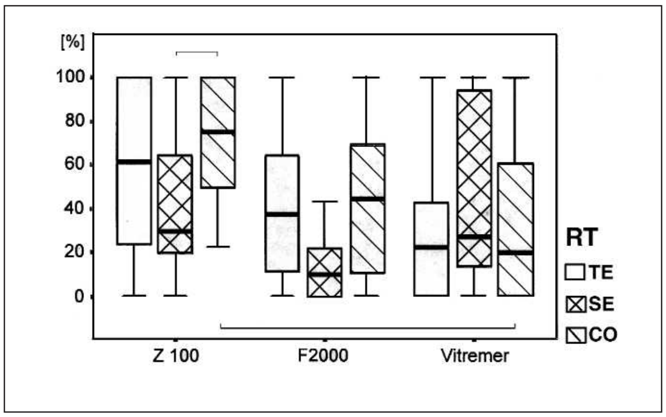

Figure 5. *Box-whisker-plots of percentages of dye penetration in the first layer, brackets on top indicate significant differences between dentin pretreatments, brackets on bottom indicate significant differences between restorative techniques (*p*<0.05).*

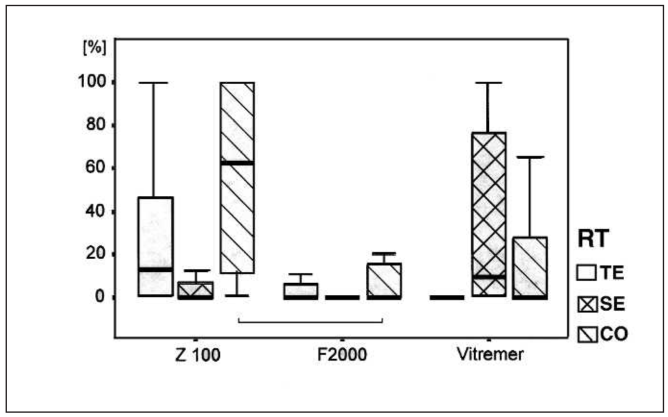

Figure 6. *Box-whisker-plots of percentages of dye penetration in the second layer, brackets on top indicate significant differences between dentin pretreatments, brackets on bottom indicate significant differences between restorative techniques (*p*<0.05).*

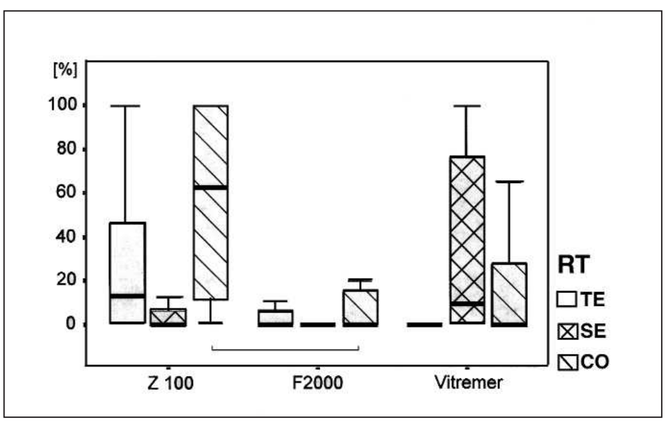

Figure 7. *Box-whisker-plots of percentages of dye penetration in the third layer, brackets on top indicate significant differences between dentin pretreatments, brackets on bottom indicate significant differences between restorative techniques (*p*<0.05).*

centages of excellent margins. However, this was mainly due to an increase in marginal irregularities since the amount of marginal openings was not significantly influenced by either pretreatment procedure.

Microleakage

The results of the dye penetration test are given in Figure 5 - Figure 7 and Table 2 for the three different layers.

All restoration types showed considerable leakage in the superficial layer. On contaminated dentin both Vitremer and F2000 sandwich restorations showed less leakage than Z100 total-bond restorations. These differences were significant for Vitremer sandwich restorations in the first and for F2000 sandwich restorations in the third layer. The contamination of the dentin increased the leakage of Z100 total-bond restorations. These differences were significant in the

Table 2: *Median Percentage Values (MDN) of Excellent Margins (EM), Marginal Openings (MO) and Dye Penetration in the FIrst (DP-1), Second (DP-2) and Third (DP-3) Layer, Interquartile Ranges (IQR) Are Given in Brackets*

group	EM		MO		DP-1		DP-2		DP-3	
	MDN	(IQR)	MDN	(IQR)	MDN	(IQR)	MDN	(IQR)	MDN	(IQR)
Z100/TE	0.0	(0.0)	53.8	(35.3)	61.1	(76.7)	10.8	(60.6)	13.1	(46.1)
F2000/TE	50.3	(88.3)	4.0	(15.3)	37.2	(53.4)	0.0	(11.0)	0.0	(5.2)
Vitremer/TE	22.7	(49.6)	0.0	(0.0)	22.4	(42.7)	0.0	(0.0)	0.0	(0.0)
Z100/SE	0.0	(0.0)	9.6	(22.3)	29.6	(44.9)	0.0	(32.6)	0.0	(5.9)
F2000/SE	50.3	(56.4)	0.0	(2.2)	9.6	(21.6)	0.0	(0.0)	0.0	(0.0)
Vitremer/SE	93.8	(34.4)	0.0	(0.0)	27.5	(80.9)	22.7	(63.3)	9.6	(76.0)
Z100/CO	0.0	(0.0)	29.5	(32.7)	75.1	(50.9)	70.1	(84.9)	62.4	(89.1)
F2000/CO	0.0	(18.6)	16.8	(32.5)	44.5	(58.8)	21.3	(30.6)	0.0	(14.8)
Vitremer/CO	20.4	(68.1)	0.0	(13.7)	20.2	(60.7)	0.0	(48.4)	0.0	(27.6)

first layer. The microleakage of Z100 total-bond restorations on contaminated dentin remained high through all three layers (median of 62.4 % in the third layer, Table 2). The microleakage of Vitremer sandwich restorations was not influenced by the contamination of the dentin.

There was a trend in all three layers for Z100 total-bond restorations to show less leakage in unetched dentin. For Vitremer sandwich restorations significantly less leakage was observed in the second layer when the dentin was acid etched compared to non-etched dentin.

DISCUSSION

Many techniques have been described to test the sealing properties of adhesive restorations in laboratory tests (Alani & Toh, 1997). One of the main difficulties of the wide spread dye penetration tests is the assessment of dye penetration at the tooth/restoration interface as a whole. Most studies analyze the depth of dye penetration on one or more perpendicular sections. Gale, Darvell & Cheung, 1994 clearly demonstrated that microleakage is a three-dimensional phenomenon and that different locations and angles of sectioning might result in completely different penetration scores. In the present study, dye penetration was qualitatively assessed and the percentage of penetration over the total margin length was calculated in three layers using a sequential grinding technique. According to the results by Gale & others, this procedure is expected to be more accurate. Furthermore, the results can be related to the results of quantitative marginal analysis in the SEM (Rauch & others, 1996). However, this assessment of dye penetration is still only semiquantitative, as it does not discriminate between severe leakage in large gaps and minimal leakage in minute gaps.

We have previously shown that the marginal adaptation of Vitremer sandwich restorations is improved when a metal matrix is used (Dietrich & others, 1999). Furthermore, the use of metal matrix bands is considered to be favorable from a practical point of view as these are easier to adapt (Hilton & others, 1997). However, the compomer and the composite used in this study are not capable of undergoing chemically activated polymerization. Therefore two subsequently polymerized increments were utilized to fill the proximal boxes for F2000/Z100 sandwich and Z100 total-bond restorations. One might be concerned that the distance between the light-tip and the cervical increment is too high to allow proper polymerization. Given a depth of a proximal box of approximately 8-10 mm, the curing light-tip will be at a distance of approximately 6-8 mm from the increment. Rueggeberg and Jordan showed that the extent of polymerization 2 mm below the increment surface is primarily dependent on exposure duration. Given a distance of 8 mm between the light-tip and the composite and a 40 second exposure as applied in this study, the monomer conversion was reduced by only 4% (Rueggeberg & Jordan, 1993). This does not explain the poor marginal adaptation of Z100 total-bond restorations observed in this study, as lower curing light-intensity results in better marginal adaptation (Unterbrink & Muessner, 1995; Lösche, 1999). However, in large teeth an additional curing step after the removal of the matrix band should ensure proper cure of the cervical increment.

In this study, all Z100 total-bond restorations showed poor marginal adaptation on cervical margins in dentin and considerable microleakage. This is in agreement with the results of previous studies (Dietschi & others, 1995; Dietrich & others, 1999). Both F2000 and Vitremer sandwich restorations showed better marginal adaptation compared to Z100 total-bond restorations on etched and non-etched dentin. These findings confirm the results of other studies and show that both resin-modified glass ionomers and compomers can improve the marginal integrity when used in a sandwich technique (Crim & Chapman, 1994; Krejci & others, 1996; Friedl & others, 1997; Dietrich & others, 1999). The initial curing shrinkage values of resin-modified glass-ionomers and compomers are comparable to those of resin composites (Attin & others, 1995). When bonded to cavity walls, the shrinking of the material results in polymerization shrinkage stress that can be reduced by various compensating mechanisms (Davidson & de Gee, 1984; Feilzer, de Gee & Davidson, 1990). The water uptake of resin-modified glass-ionomers is substantially higher than that of resin composites, while compomers are intermediate (Martin & Jedynakiewicz, 1998; Small & others, 1998). This corresponds with hygroscopic expansion and shrinkage stress relief (Attin & others, 1995; Feilzer & others, 1995b). Furthermore, the use of one proximal increment of Vitremer in combination with a metal matrix is likely to result in higher flow compensation of shrinkage stress due to lower curing light intensity (Feilzer & others, 1995a; Dietrich & others, 1999). Finally, porosity in the hand-mixed Vitremer may have contributed to lower shrinkage stress (Alster & others, 1992).

There are various different ways to deal with a contamination during the bonding procedure in a clinical situation that have been shown to influence bond strength to contaminated surfaces (Fritz, Finger & Stean, 1998). In the present study, the surface was gently air dried after saliva contamination and again after blood contamination. No rinsing or re-etching was performed in order simulate a "worst case scenario" to investigate differences between the materials that might be clinically relevant. Although it cannot be ruled out that blood remnants might have been mistakenly scored as dye in the penetration test, this is very unlikely because significant differences were detected between the material groups and minimal leakage was observed in F2000 and Vitremer sandwich restorations in the third layer (Figure 5 - Figure 7).

An increasing number of studies suggest that modern hydrophilic dentin bonding systems might be less sensitive to saliva contamination during bonding procedures (Xie, Powers & McGuckin, 1993; Johnson & others, 1994; El-Kalla & García-Godoy, 1997; Fritz & others, 1998). However, significantly lower bond strength of composite to blood contaminated dentin surfaces with various adhesives have been reported (Abdalla & Davidson, 1998), while two studies indicate that resin-modified glass-ionomers might be less sensitive to contamination with blood and saliva (Feilzer & others, 1997; Momoi & others, 1997). In this investigation, Z100 total-bond restorations on contaminated dentin showed severe microleakage that, in contrast to all other groups, did not decrease towards the deeper parts of the cavity. F2000 sandwich restorations showed significantly more marginal openings on contaminated dentin compared to uncontaminated dentin. These results indicate that the bonding capacity of Scotchbond 1 was substantially reduced by the contamination with saliva and blood, and confirm the results of Abdalla et al (Abdalla & Davidson, 1998). Vitremer sandwich restorations showed significantly less excellent margins on contaminated dentin mainly due to higher amounts of marginal irregularities (Figures 3 and 4). The microleakage of Vitremer sandwich restorations was not influenced by the contamination of the dentin. After contamination with saliva and blood, Vitremer sandwich restorations showed significantly better marginal adaptation (Figures 3 and 4) and both F2000 and Vitremer sandwich restorations showed less microleakage (Figures 5 and 7) than Z100 total-bond restorations. These results indicate that resin-modified glass-ionomers and compomers are less sensitive to contamination than resin composites. The underlying mechanisms are unclear, however hygroscopic expansion is likely to play a significant role, as it has been shown to compensate for initial debonding (Fritz, Finger & Uno, 1996).

The finding that total-bond restorations with Scotchbond 1/Z100 showed significantly higher percentages of marginal openings when the cervical dentin was acid etched compared to non-etched dentin was unexpected. There was also a trend for such restorations to show more microleakage in all three layers. The complete infiltration of the demineralized collagen network with primer/adhesive monomer is considered to be of utmost importance for a stable dentin/adhesive bond. It has been hypothesized that this might not occur when the dentin is excessively demineralized (Tam & Pilliar, 1994). Significantly thicker hybrid layers and lower bond strength have been reported with longer etching times (Nör & others, 1996; Uno & Finger, 1996; Pioch & others, 1998) and higher acid concentrations (Tam & Pilliar, 1994). Recently Peschke, et al reported a deleterious effect of a prolonged (60 seconds) acid etching of the dentin on the marginal adaptation of Optibond FL/Prodigy Class V restorations compared to a 15 seconds etching time. Such restorations even showed worse marginal adaptation than restorations where the dentin was not at all acid etched (Peschke, Blunck & Roulet, 1998). The total-etch technique requires the etching of both enamel and dentin at one time. It is usually recommended to start the etching procedure with enamel to ensure proper etching of the enamel while avoiding too long etching times of the dentin. However, in large Class II MOD cavities with two proximal boxes, a prolonged etching of at least part of the dentin is very likely to occur and might be the explanation for the results obtained in this study.

Recently, Roussel and others reported low microleakage on cervical dentin with F2000/Z100 sandwich Class II restorations when F2000 Compomer Primer/Adhesive was used (Roussel, Zeboulon & Randall, 1998). However, the manufacturer leaves it to the discretion of the practitioner whether to use the F2000 Compomer Primer/Adhesive or a "universal" adhesive system, such as Scotchbond 1 to bond F2000 to tooth structures. In the present study, F2000 was used with Scotchbond 1 since the sandwich technique is considerably simplified by the use of the same adhesive for the compomer and the composite. Various factors have been suggested that may contribute to the adhesion of resin-modified glass-ionomers to dentin (Lin, McIntyre & Davidson, 1992). However, since these materials contain resinous components, they have been used in combination with resin bonding systems (Vargas, Fortin & Swift, 1995; Fritz & others, 1996; Pereira & others, 1998). This approach is particularly tempting when considering the sandwich technique, as it would substantially simplify the clinical procedure. Vitremer sandwich restorations showed the highest percentages of excellent margins on unetched dentin. However, the amount of marginal openings did not significantly increase when the dentin was acid etched. Glasspoole and Erickson reported significantly lower bond strength of Vitremer to etched dentin (Glasspoole & Erickson, 1995) but in a recent study these authors found that bond strength to etched dentin may be ameliorated by a wet bonding technique (Erickson & Glasspoole, 1998). It is interesting to note that while showing significantly higher percentages of excellent margins, Vitremer sandwich restorations on unetched dentin showed significantly more microleakage than on etched dentin in the second and third layer. Obviously, marginal adaptation does not necessarily correspond with microleakage. In a previous study, Kostka directly compared the marginal adaptation and microleakage of adhesively luted ceramic inlays by evaluating multiple sections at precisely the same locations. He found that margins with a detectable gap showed microleakage both in enamel and dentin. The depth of dye penetration was not dependent on the width of the marginal opening. Margins with no detectable gap showed no microleakage, however, the author stated that the most commonly used magnification of 200x was sometimes not sufficient to detect small gaps (<1µm) (Kostka, 1996). These results were confirmed by Rauch et al for Class V composite fillings (Rauch & others, 1996). However, the results of the present study indicate that this relationship does not necessarily hold for all material types. The relationship between marginal adaptation and microleakage as measured in this study seems to be dependent on the restorative material and the bonding procedure. Water-sorption is a time dependent process. Gaps that occur due to debonding subsequently to polymerization may later be filled by hygroscopic expansion (Fritz & others, 1996). This might happen to such an extent that they are undetectable under SEM at a given magnification but show leakage in a penetration test.

The fact that Vitremer sandwich restorations with a selective etch showed a median of 93.8% excellent margins and 0.0 % marginal openings on one hand, but showed a similar amount of microleakage as Z100 total-bond restorations on the other hand, underlines a basic problem of laboratory testing of restorative materials. The interpretation of such laboratory tests in terms of clinical relevance is difficult because there is currently no scientifically validated means of correlating the results of laboratory tests with clinical outcome (Roulet, 1994; Sudsangiam & van Noort, 1999). Criteria or terms like "satisfactory" or "acceptable" marginal adaptation should therefore be avoided when marginal adaptation is assessed in the SEM. Furthermore, both microleakage and marginal adaptation should be determined in laboratory tests of adhesive restorations, particularly when different material types are compared.

CONCLUSIONS

Both F2000/Z100 and Vitremer/Z100 sandwich restorations show better marginal adaptation than Z100 total-bond-restorations in large Class II cavities with cervical margins in dentin. This difference was less pronounced with respect to microleakage. Microleakage could not predictably be prevented with the sandwich technique.

The results of this laboratory study indicate that sandwich restorations might be less sensitive to contamination with saliva and blood during the bonding procedure. This aspect of sandwich restorations merits further investigation.

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Bonded Amalgam Restorations: Using a Glass-Ionomer as an Adhesive Liner

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Clinical Relevance

Fuji-II glass-ionomer cement, when used as an adhesive liner for amalgam restorations, may effectively reinforce the remaining tooth structure and, therefore, enhance the fracture resistance of the amalgam-restored teeth.

SUMMARY

Due to the lack of adhesiveness of amalgam to tooth structure, several adhesive cements have been utilized in bonded amalgam restorations. This study evaluated whether Fuji-II glass-ionomer cement is an appropriate adhesive liner in bonded amalgam restorations. Two adhesive composite luting cements (Amalgambond Plus and Panavia-2l) and Copalite cavity liner were compared. The study was conducted in two phases. In the first part, we quantitatively assessed the tensile bond strengths as well as the failure modes of amalgam bonded to human dentin, using different adhesive liners. In each group, the flat dentin surface was treated with the assigned adhesive cement with a Teflon mold, followed by condensation of amalgam (Valiant PhD) onto it. Each group's mean tensile bond strengths were recorded and the statistical analysis by one way ANOVA showed no significant differences among groups ($p>0.05$). Similar to the fracture patterns of the Amalgambond Plus and Panavia-21 groups, the failure mode of Fuji-II group was predominantly adhesive fracture. In the second part, the fracture strengths of amalgam restored teeth were measured using different adhesive liners. Standard MOD cavities were prepared in each tooth except for the intact tooth group. After treatment with the assigned adhesives or varnish, the cavities were restored with amalgam. Fracture strengths were then measured and the fractured interfaces examined using a scanning electron microscope. The fracture strengths of the intact tooth, Amalgambond Plus, Panavia-2l and Fuji-II groups were significantly higher than those of the Copalite and prepared cavity without restoration groups ($p<0.01$). Accordingly, Fuji-II glass-ionomer cement, when used as an adhesive liner of amalgam restoration, may effectively reinforce the remaining tooth structure and, therefore, enhance the fracture resistance of the amalgam-restored teeth.

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INTRODUCTION

Dental amalgam has been used as a restorative material for more than 150 years. Advantages include good physical properties, dimensional stability, ease of manipulation and nearly insolubility in the oral cavity (Craig, 1985). While some authors have recently suggested that composite resin materials may replace amalgam as a restorative material, amalgam is still the restorative material of choice for the posterior teeth (Curtis & Brown, 1992). However, some drawbacks of amalgam restoration have been reported, such as post-operative tooth sensitivity (Mahler & Nelson, 1994) and the susceptibility to fracture of amalgam restored teeth (Boyer & Roth, 1994). A major reason for this is amalgam's lack of adhesiveness to dental substrates (Gwinnett & others, 1994). Cavity design with mechanical retention is, therefore, required for the amalgam restorations at the expense of healthy tooth structure (Staninec & Holt, 1988).

Bonding of amalgam to tooth structure under the application of adhesive materials, the so-called "bonded amalgam restoration," provides a new regimen in operative dentistry (Smales & Wetherell, 1994; Lacy & Staninec, 1989). Current adhesive materials, such as Panavia-21 and Amalgambond Plus, contain bi-functional molecules that have an affinity for metal at one end and an affinity for monomers at the other (Curtis & Brown, 1992). The advantages of bonded amalgam restoration include better retention of the restored amalgam, higher fracture resistance and less microleakage, secondary caries and post-operative sensitivity of the restored teeth (Gwinnett & others, 1994; Smales & Wetherell, 1994; Christensen, 1994). However, manipulation procedures of these materials are generally complicated and technique sensitive.

Glass-ionomer cements were first formulated in the early 1970s (Wilson & Kent, 1972). The important physical and chemical properties that make glass-ionomer cements appropriate restorative materials, base materials and luting agents are: (1) chemical bond to dental hard tissues, reducing the need for retentive cavity preparation (Wilson, Prosser & Prowis, 1983; Nicholson & Croll, 1997); (2) fluoride releasing over a long period of time, which helps prevent secondary caries (Walls, 1986; Swartz, Phillips, & Clark, 1984; Nagamine & others, 1997; Dionysopoulos & others, 1998); and (3) good compatibility with pulp tissues. It can also bond to metallic-oxide, such as tin-oxide and silver-oxide (Hotz & others, 1977). Since tin and silver are major components of dental amalgam, the bonding of glass ionomer to amalgam is, therefore, highly expected. Mojon & others (1989) demonstrated that glass ionomer is an appropriate material for amalgam repair. Although previous reports have shown that chemical-curing and light-curing glass-ionomer cements form strong adhesive bonds with set amalgam (Aboush & Jenkins, 1989; Aboush & Elderton, 1991), little work has been reported on bonding glass-ionomer cements to unset amalgam. This study specifically evaluated a glass-ionomer cement and two resin composite luting cements as adhesive liners in bonded amalgam restorations and compared them to a copal varnish liner.

METHODS AND MATERIALS

This study was conducted in two phases to investigate whether glass-ionomer cement is an appropriate lining material in bonded amalgam restorations. In the first part, the tensile bond strengths between the bonded amalgam and dentin, as well as the failure modes, were analyzed; whereas in the second part, measuring the fracture strengths of amalgam restored teeth using the glass ionomer as an adhesive liner were evaluated. For comparative purposes, two currently available adhesive resin luting cements and a cavity varnish were used.

Part 1: Tensile Bond Test and Fractography

Ninety noncarious human molars were selected and stored in 4°C distilled water until use. Each tooth, after being embedded in a resin, was trimmed along the occlusal plane. A flat dentin surface with a diameter greater than 8 mm was prepared by grinding on 320-grit and 600-grit Si-C papers. These teeth were then randomly divided into three groups of 30 specimens each according to the assigned adhesive cements: Amalgambond Plus (S370, Parkell, Farmingdale, NY 11735), Panavia-21 (51266, Kuraray Co, Ltd, Osaka, Japan), and Fuji-II self-cured glass-ionomer cement (271071, GC Co, Tokyo, Japan).

In each group, a disposable Teflon mold (7 mm in length, 4.5 mm in diameter at one end and 7 mm in diameter at the other) was set on the flat dentin surface by an adhesive tape. The 4.5 mm end of the Teflon mold was faced to the dentin surface. The assigned adhesive cements were mixed and manipulated according to manufacturer's instructions. After a thin layer (0.1~0.3 mm) of the assigned cement was applied to the dentin surface, an admixed type amalgam (Valiant PhD 060400, Caulk-Dentsply, Milford, DE 19963) was condensed into the Teflon mold. All specimens were left undisturbed and stored in 37°C distilled water for seven days.

The specimens were then mounted on a universal-testing machine (Autopulse, TC 500, China Material Technology & Science Co, Taipei, Taiwan, ROC) for tensile bond test at a crosshead speed of 0.5 mm/min. During debonding, the applied load versus displacement of the load fixture was recorded and analyzed automatically by a data acquisition system (CMS 3000X, China Material Technology & Science Co, Taipei, Taiwan, ROC).

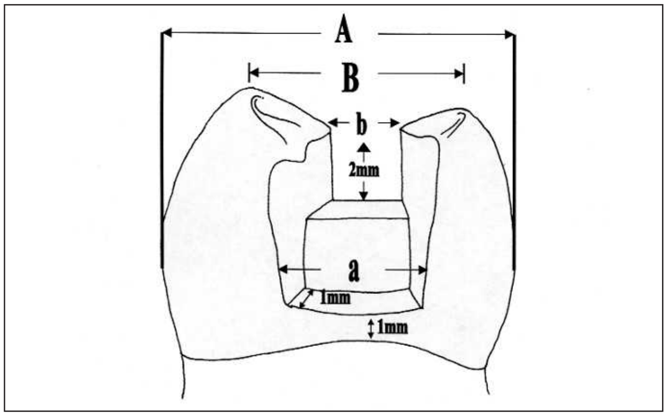

Figure 1. *Diagrammatic illustration of mesial-occlusal-distal cavity preparation. A: width of the tooth at the buccal-palatal direction measured from height of contour; B: inter-cuspal tips width; a=1/3 A; b=1/3B.*

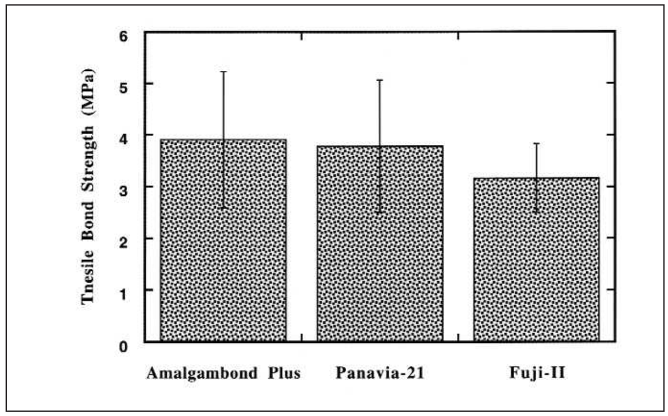

Figure 2. *Mean tensile bond strengths and standard deviations for Amalgambond Plus, Panavia-21 and Fuji-II.*

Following rinsing in phosphate buffered saline, the debonded specimens were fixed with 2.5% glutaraldehyde in 0.1 mol/L sodium cacodylate buffer, pH 7.4, for four hours. All specimens were dehydrated in an ascending ethanol series, then processed by critical point drying. The specimens were then sputter coated with gold using a Polaron automatic sputter coater (SC502, Bio-Rad, Cambridge, MA 02021). Scanning electron microscopic examination was performed using a Topcon ABT-60 (Topcon, Tokyo, Japan) to determine any textural differences and the failure modes at the fracture surfaces.

Part 2: Fracture Strengths of the Amalgam-Restored Teeth

Seventy-two intact human maxillary premolars, extracted within three months, were selected and stored in 4°C distilled water until used. Each tooth was mounted in an aluminum ring using orthodontic clear resin, leaving 2 mm of the cervical root surface exposed, approximating the support of alveolar bone *in vivo*. All teeth were then randomly divided into six groups of 12 teeth each, according to the lining materials used.

The intact tooth group received no treatment as a negative control. A standard MOD cavity, Figure 1, was prepared in each tooth of the remaining five groups. The positive control group received only the cavity preparation without any liner and amalgam restoration. One of the following liners was used in each of the remaining groups: Amalgambond Plus (Parkell, Farmingdale, NY 11735), Panavia-21 (Kuraray Co, Ltd, Osaka, Japan), a cavity varnish-Copalite (Cooley & Cooley, Ltd, Houston, TX 77041) and a glass-ionomer cement Fuji-II (GC Co, Tokyo, Japan). All cavity liners were manipulated according to the manufacturer's instructions. After lining, the cavities were restored with an admixed type amalgam (Valiant PhD 060400, Caulk-Dentsply, Milford, DE 19963).

Once the restorations were completed, all specimens were left undisturbed for 15 minutes, then stored in 37°C distilled water for seven days. Each specimen was placed on a universal-testing machine (Autopulse, TC 500, China Material Technology & Science Co, Taipei, Taiwan, ROC) under the working mode of "Compression." The crosshead speed was 0.5 mm/min. A steel sphere with a diameter of 5 mm was rigidly attached to the upper cross-member and brought into a position with contact to both the buccal and palatal inclinations of cusps and no contact with the amalgam. The applied load versus displacement of the load fixture was automatically recorded by a data acquisition system (CMS 3000X, China Material Technology & Science Co, Taipei, Taiwan, ROC), providing the maximal fracture strength information. ANOVA and Scheffe's posteriori comparison analyzed the differences of fracture strengths among groups.

RESULTS

Part 1: Tensile Bond Test and Fractography

Figure 2 shows each group's mean tensile bond strengths. Although the mean tensile bond strength of the Fuji-II group (3.16 ± 0.66 Mpa) was somewhat lower than those of the Amalgambond Plus (3.91 ± 1.32 Mpa) and Panavia-21 (3.78 ± 1.28 Mpa), the differences among them were not significant by one way ANOVA test (p>0.05).

Fractographic study indicated that the fracture paths were situated in either the cements or amalgam, or along the interface between dentin and cements. The fracture modes of Amalgambond Plus group were mainly adhesive failure in the amalgam/Amalgambond Plus interface. The fracture modes of Panavia-21 group were mainly cohesive failure of Panavia-21 and adhesive failure between dentin and Panavia interface. Similar to the fracture patterns of the Amalgambond Plus group, the failure mode of the Fuji-II group was predominantly adhesive fracture, either through the adhesive or along

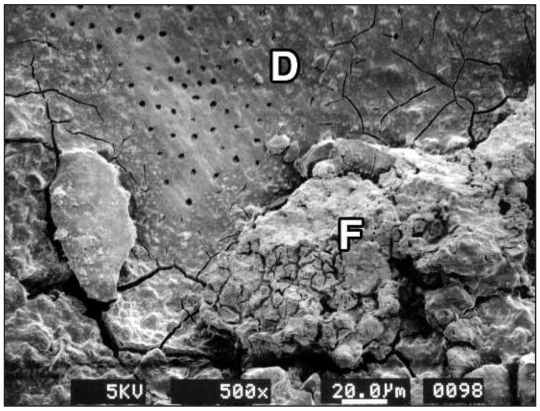

Figure 3. *Scanning electron micrograph of the fracture surface on dentin side of Fuji-II group showing some Fuji-II remnants left at the debonded dentin surface. D: dentin; F: Fuji-II.*

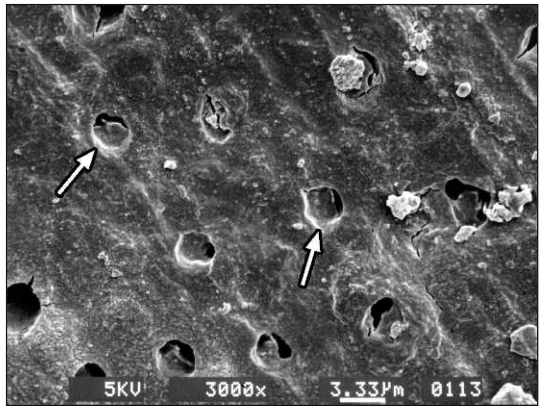

Figure 4. *Magnification of fracture surface on dentin side of Fuji-II group showing the tags of the Fuji-II glass-ionomer cements in dentinal tubules (arrows).*

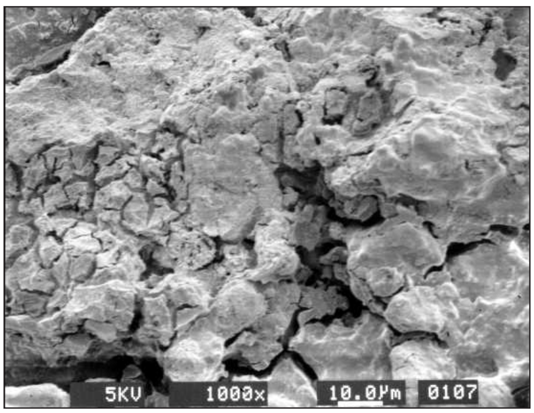

Figure 5. *Magnification of fracture surface on dentin side of Fuji-II group showing intimate interlocking of glass-ionomer cements and amalgam particles that resulted from condensing amalgam onto the unset glass ionomer.*

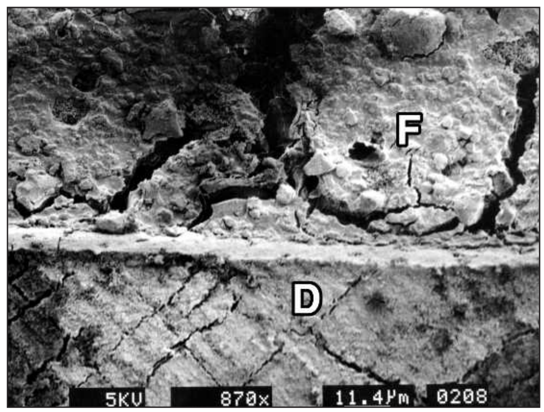

Figure 6. *Scanning electron micrograph of mesiodistal section of the amalgam restored teeth, showing close adaptation of Fuji-II glass-ionomer liner to dentin. D: dentin; F: Fuji-II.*

the interface between dentin and adhesive with some Fuji-II remnants left on the debonded dentin surface (Figure 3). At higher magnification, the tags of the Fuji-II glass-ionomer cements in dentinal tubules were observed (Figure 4). Magnification of the fractured Fuji-II remnants also revealed intimate interlocking of glass-ionomer cements and amalgam particles that resulted from condensing amalgam onto the unset glass ionomer (Figure 5).

Part 2: Fracture Strengths of the Amalgam Restored Teeth

Table 1 lists the mean fracture strength of each group. The results of the statistical analysis are shown in Tables 2 and 3. The mean fracture strengths showed no statistical differences among the groups of intact teeth, Amalgambond Plus, Panavia-21 and Fuji-II. The positive control group, in which cavity preparation was performed without restoration, showed no statistical difference to the Copalite group. However, the fracture strengths of the intact teeth, Amalgam-bond Plus, Panavia-2l and Fuji-II groups were significantly higher than the Copalite and positive control groups.

SEM micrograph of mesiodistal section of the amalgam restored teeth shows close adaptation of Fuji-II glass ionomer liner to dentin (Figure 6). In some instances, the dentin/glass ionomer/ amalgam interface with separation at the glass ionomer liner/dentin junction is observed (Figure 7). This may be due to the dehydration during specimen preparation. Glass ionomer is seen extending into the amalgam with which it interlocks. The thickness of the condensed Fuji II glass ionomer is about 20~30μm.

DISCUSSION

Using adhesive cements in amalgam restorations is a new regimen to improve the bonding of amalgam to tooth structures. It has been reported that microleakage is effectively reduced and the fracture resistance markedly reinforced in bonded amalgam restorations (Smales & Wetherell, 1994; Christensen, 1994) due to the fact that bonding between amalgam and tooth structures is greatly improved by using adhesive cements. Previous studies demonstrated that when using Amalgambond and Panavia EX as adhesive cements to bond amalgam to dentin, the tensile bond strengths were in the range of 3~4 MPa (Nakabayashi, Watanabe & Gendusa, 1992; Barkmeier, Gendusa & Thurmond, 1994; Aboush & Jenkins, 1991). In this study, the mean tensile bond strengths of the Panavia-21 and Amalgambond Plus groups were within this range. The results also showed that the mean tensile bond strength of Fuji-II group was as strong as the Panavia-21 and Amalgambond Plus groups.

Table 1: *Mean Fracture Strengths*

Group	Mean(kg)	SD
Intact tooth	135.1	18.7
Cavity prepare only	57.2	8.6
Copalite	69.5	31.9
Amalgambond Plus	120.6	37.6
Panavia-21	116.9	41.6
Fuji-II	121.4	33.4

Table 2: *Analysis of Variance Table*

Source	DF	SS	MS	F	p
Between groups	5	59375.54	11875.1	12.37	<0.05
Within	66	63368.06	960.12		
Total	71	122743.6			

DF: Degree of Freedom
SS: Sum Squares
MS: Mean Squares

Table 3: . *Scheffe's Posteriori Comparison*

Group	I	C	A	P	F
C	25.7*				
A	1.31	15.6*			
P	2.07	13.4*	0.09		
F	1.22	16.7*	0.004	0.13	
M	37.9*	0.9	25.1*	22.3*	26.8*

I: Intact tooth (Negative control); C: Copalite; A: Amalgambond Plus;
P: Panavia-21; F: Fuji-II; M: MOD cavity preparation without restoration (Positive control);
* Significant difference (p<0.05)

Amalgam's lack of adhesiveness to tooth structure requires cavity preparation that provides additional mechanical locking for retention. Knowing that adhesive cements enhance the bonding of amalgam to dentin could help dental practitioners be more conservative in cavity preparation. According to the results of previous studies (Watts, El Mowafy & Grant, 1987; Joynt & others, 1987; Jagadish & Yogesh, 1990), cavity preparation could reduce 1/2 to 3/4 of the original strength of the tooth, which is consistent with the results of our study. The mean fracture strengths of the Amalgambond Plus, Panavia-21 and Fuji-II groups showed no statistical differences to the intact tooth. This means that using an adhesive liner may improve the strength of amalgam-restored teeth. Bell, Smith & de pont (1982) applied a finite element model to analyze the stress distribution of MOD cavity-prepared teeth and concluded that stress concentrated areas were located at the floors and the line angles of the cavity. In this study, fracture of cavity-prepared teeth always occurred along the line angle of the pulp wall via the axial wall to gingival wall, leading to a total cusp fracture. Although using adhesive materials can strengthen the bonding between amalgam and tooth structure, the interface remains a potential weak point, and the risk of fracture still exists no matter what kind of adhesives are used. Unlike the adhesive groups, intact teeth revealed only point fracture at cusp inclination, where the force was loaded. The group using Copalite as a cavity varnish showed no effect of tooth reinforcement.

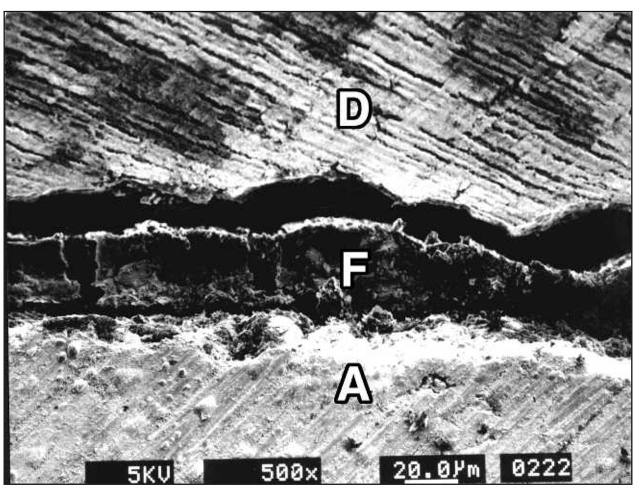

Figure 7. *Scanning electron micrograph of mesiodistal section of the amalgam restored teeth. In some instances, the dentin/glass ionomer/amalgam interface with separation at the glass-ionomer liner/dentin junction is observed. Glass ionomer is seen extending into the amalgam with which it interlocks. The thickness of the condensed Fuji II glass ionomer is about 20 ~30µm. A: amalgam; D: dentin; F: Fuji-II.*

Fracture along and adjacent to biomaterial interfaces has several manifestations (Dalgleish, Lu & Evans, 1988). In an adhesive joint, the failure plane may situate either in the materials forming the joint, along the interface or wandering between these possible paths. The total fracture strength may be influenced not only by the interfacial strength, but also the strength of cohesive-in-adhesive and cohesive-in-substrate (Kinloch, 1990). Understanding the failure mode is of prime importance for predicting the failure mechanisms of a bond. In this study, the failure modes observed were either of the adhesive type, through the interface of adhesive/amalgam or adhesive/dentin, or cohesive failure of the adhesive, itself. The differences in fracture patterns among groups could be explained by the differences in the setting reactions of these cements.

From the SEM observations of the tooth-restoration interface, some differences among groups were noted. In the Amalgambond Plus group, a layer of adhesive could be found between the amalgam and tooth structure. This adhesive cement showed higher affinity to the tooth rather than to the amalgam. This phenomenon may be explained by the short setting time of the Amalgambond Plus. In other words, the fast-setting property makes it bond to the tooth structure better than to amalgam. For Panavia-21, due to its specific composition, it remained unset throughout the entire restoration. This explains the SEM photographs showing the adhesive layer loosely adhering to the amalgam and tooth structure. In the Fuji-II group, the interfacial layer was composed of amalgam and Fuji-II. The condensed amalgam intermingled with the Fuji-II and resulted in a mixed layer. As for the Copalite group, no remnants could be observed on the fractured specimens.

Amalgambond Plus was specially developed for bonding amalgam to enamel and dentin. It is based on the 4-META/MMA-TBB adhesive resin system. Nakabayashi & Takarada (1992) demonstrated that 4-META/MMA-TBB adhesive resin cement could effectively bond to the hydroxyapatite and collagen network of dentin. The addition of high performance additives to the Amalgambond Plus system would improve the strength and prolong the setting time. However, the short working time makes it difficult to handle, which would affect the bonding of amalgam to Amalgambond Plus. This could be why Amalgambond Plus was always found on the fractured dentin surface.

Panavia-21, a Bis-GMA based phosphonated anaerobic adhesive, is a two-paste adhesive system. Manipulation of the magnitude of both base and catalyst can decrease the incorporation of air during mixing and increase the physical properties of the cement. It has been proven to have affinity to both metals, such as amalgam and tooth structure. Unlike Amalgambond Plus, Panavia-21 remained unset during the whole amalgam condensation procedure. The adhesive was highly flowable and could be squeezed out of the interface.

Fuji-II is a chemical-curing glass-ionomer cement. During the condensation of amalgam, the cement is still in the early-set stage that flows moderately and intermingles with the amalgam. The interlocking is probably more important for amalgam retention than the chemical bonds between the ionomer and the components of the amalgam.

Mojon & others (1989) demonstrated that the bond between adhesive resin and amalgam is stronger and more reliable than the Aqua Cem glass-ionomer bond. Aboush & Jenkins (1989) claimed that the chemical-curing glass ionomers gave slightly lower mean bond strength values to the set amalgam, and the bonds fractured cohesively through the cement. In another study, Aboush & Elderton (1990) tried to apply light-curing glass ionomers, with higher cohesive strength than chemical-curing glass ionomers, to bond to set amalgam. Our study investigated the bonding of amalgam to dentin in which a fresh mix of unset Fuji-II chemical-curing glass ionomer was used as an intermediary. In this situation, mechanical bonds and chemical bonds were established in the intermingled unset glass ionomer and amalgam. The results of this study showed that bonding Fuji-II glass ionomer to amalgam was as strong as those of the Amalgambond Plus and Panavia-21. Having the advantages of easy manipulation, prolonged fluoride release and low pulpal irritation, Fuji-II glass-ionomer cement may be considered an appropriate liner for bonding amalgam to tooth structure.

CONCLUSIONS

Fuji-II glass-ionomer cement, when used as an adhesive liner for amalgam restorations, showed similar strengthening effects for restored teeth when compared with the Amalgambond Plus and Panavia-21. The junction between amalgam and tooth structure is a potential weak point of the restored tooth, and the risk of fracture still exists. Copalite varnish showed no effect on the fracture strength of the amalgam-restored teeth. From the SEM fractographic study, different fracture patterns, which could be explained by the different setting reactions of the materials, were found. In view of clinical practice, the early-set stage of Fuji-II is more convenient for the condensation of amalgam. Therefore, it appears that glass-ionomer cement can be considered an appropriate adhesive liner in bonded amalgam restorations.

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In Vivo Examination of the Scotchbond Multi-Purpose Dental Adhesive System in Rat (Vitalmicroscopic Study)

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L Rosivall • I Nyárasdy

Clinical Relevance

Resin composite bonding agents applied directly onto a thin layer of dentin showed acute vasodilating effects on rat pulpal microvessels.

SUMMARY

No data are available on the direct acute vascular effect of dental bonding materials on the dental pulp. This study investigated the effects of the components of a composite resin-bonding system on pulpal vascular diameter. Three groups of 10 male Sprague-Dawley rats (weighing 330 ± 51 g) were used for this investigation. The first lower incisor of the rats was prepared for vitalmicroscopy. Changes in vessel diameter were recorded prior to, and at 5, 15, 30 and 60 minutes after the bonding agents (with/without etching) or saline (control) were administered on dentin as recommended by the manufacturer. In control rats, the vessel diameter was elevated slightly (2.96 ± 4.08%) during the whole experiment. However, in the presence of bonding materials, an enhancement of 12.58 ± 7.1% without etching and 13.11 ± 8.6% with acid etching was registered as the increase in vascular diameter. There were significant (*p*<0.05) differences between the control group and those treated with bonding agent components. Results suggested that resin composite bonding agents applied to a thin layer of dentin have an acute vasodilating effect on the dental pulp. The clinical significance of this vascular alteration in the dental pulp requires further study.

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INTRODUCTION

Recently, there has been a rapid increase in the use of polymers and resin composites for dental purposes. Despite great progress in the production of new dental polymers, the best way to apply these products is still controversial. Some are concerned with toxicological and allergic problems. Resin composite materials and conditioning agents are chemically active compounds and may have deleterious effects on the pulp (Hörsted & others, 1986; Quist & others, 1989; Fuks & Cleaton, 1990; Elbaum & others, 1992; Stanley, 1992; Al-Dawood & Wennberg, 1993). The biocompatibility of restorative resins is an important international issue. However, no data are available on the direct acute vascular effect of dental resin materials on the dental pulp. Histopathological tests have been established to evaluate the biocompatibility of restorative resins *in vivo* (Mjör,

1985) by the American Dental Association (ADA) and are outlined in its clinical usage guidelines. The Fédération Dentaire Internationale (FDI) biologic usage *in vivo* testing specifications, published in the International Standards Organisation/Technical Committee (ISO/TC, 1992; Stanley, 1994; Stanley, 1992) document have also been established. However, these tests may not serve as a model for continuous qualitative and quantitative studies of acute vascular changes on the living pulp in its normal relationship within the animal. Besides, the confounding variable of bacterial microleakage creates a difficulty with the histopathological evaluation (Quist, 1993). Thus, the investigation of the early signs of the acute inflammation of the living pulps of rats *in vivo* after application of dental materials provides valuable supplemental information to the findings of the recommended ADA, FDI and ISO *in vivo* usage tests.

A concept for pulpal vitalmicroscopy was first proposed by Taylor (1950), who investigated the dental pulp of dogs, monkeys, cats and rats, and found that the pulp of a rat was the most suitable for observation of pulpal circulation. Kim & others (1984) performed the first hemodynamic measurements by modifying the method of Pohto & Scheinin (1958). Applying a camcorder and a monitor, they were able to measure the diameter of the vessels, thus presenting one of the most essential hemodynamic parameters.

Medications and dental materials, applied as liners and filling materials, were first investigated on rat incisors by vitalmicroscopy by Gängler (Gängler & Pilz, 1974a; 1974b; Gängler, 1976a; Gängler & others, 1982). Nyárasdy (1990) investigated various composite filling materials.

METHODS AND MATERIALS

This study was performed, as described by Taylor (1950), and modified by Pohto & Scheinin (1958), Kozam & Burnett (1959), Gängler & others (1976b, 1982) and Krehan & others (1984). It determined whether the components of the Scotchbond Multi-Purpose Dental Adhesive System 3M (primer and adhesive applied with or without etchant) alters the blood circulation of the pulp of the rat lower incisor by applying it (without any liner) directly onto a thin layer of dentin (20-40 µm) and following the manufacturer's instructions.

Materials

Scotchbond Multi-Purpose Primer, which contains HEMA (2hydroxyethylmethacrilate) and watered solution of Vitremer copolymer; Scotchbond Multi-Purpose Adhesive, which contains HEMA and BIS-GMA (Bisphenol A glycidyl methacrylate), separately and with Scotchbond etchant (10% by weight maleic acid), were used as recommended by the manufacturer (3M Dental Products, St Paul, MN 55144-1000) in the two test groups.

Animal Preparation

The study examined three groups of 10 male Sprague-Dawley rats (weighing 330 ± 51 g). The rats were anesthetized with pentobarbitone sodium (Nembutal 35 mg/kg ip). Breathing was facilitated by tracheal cannulation, and a heparinized (1500 IU/ml) polyethylene catheter was inserted into the left femoral artery to measure arterial blood pressure. Throughout the experiment, body temperature was maintained at 37°C using a heating lamp. Depth of anesthesia was evaluated by applying pressure to a paw and observing changes in blood pressure. When such changes occurred, additional anesthetic was administered. From the left part of the lower jaw, the mucous membrane was retracted and the jaws separated by transecting the connective ligaments between the lower jaws. The left part of the lower jaw was fixed with a circular polyester strip used in dentistry to avoid the irritating and traumatizing effect of circular metal strip. With the teeth thus firmly held, the mesial and distal surfaces of the incisor and some part of the alveolar bone were ground away with a dental bur. The excavation was made on the mesial and distal surfaces from the labial to the lingual margins and from the alveolar bone to the incisal edge, as described previously by Krehan & others (1984). Grinding was done at about 15000 rpm (Swedlow & Stanley, 1959) with a diamond fissure bur and the applied pressure was kept minimal (Stanley, 1993). During preparation, the exposed dentin was kept at a constant temperature (37°C) using a saline solution (Gängler & others, 1979; Gängler & Langeland, 1981). After removing the enamel and part of the alveolar process, preparation was done under a dissecting binocular microscope (1.6x6.3) until the pulp vessels became clearly visible through the remaining dentin. When grinding was complete, a thin plate of dentin (approximately 20-40 µm in thickness) still remained intact over the delicate pulpal tissue.

After preparation, the rat was placed on its right side on a suitable animal board attached to the stage of a Nikon stereo light microscope (10x0.255 + 1x16) equipped with a video camera and an image amplifier (500x–Sony CCD-IRIS). The exposed dentin was kept wet at a constant temperature by a thermostat-driven continuous saline rinse.

After a one-hour equilibration (Gängler, 1976), a suitable arteriole (40 ± 2 µm) was chosen for the measurement of its inner diameter, and this baseline vessel diameter was recorded on video. Subsequently, the bond material (test groups: with or without etching) or saline solution (control animals) was administered on the prepared surface.

The vessel diameter was measured on the monitor with the help of a calliper gauge (on the screen 1 mm ≅ 2 µm in the pulp) after 5, 15, 30 and 60 minutes. The diameter changes compared to the baseline diameters were calculated in each examined time. Results were evaluated with one-way ANOVA. A significant level less than or equal to 0.05 was chosen to indicate statistical significance. In each group, averages of diameter changes (compared to the baseline diameters) and standard errors of the mean were calculated for each examined time.

RESULTS

In the control and test groups, the systemic arterial pressure measured in the femoral artery (85 Hgmm–110 Hgmm) were practically unchanged during the examined time.

Results are expressed as average ± standard error. During control conditions, the observed mean-vessel diameter (38.6 ± 1.22 μm) increased slightly (2.96 ± 4.08%) during the experiment. The averages of the control measurements in different time periods were used for comparison with experimental data.

A vasodilating effect of the materials on rat pulpal vessels was observed in all test groups. The vessel diameter changes were elevated compared to those of the untreated control group. In the test group with acid etching (Figure 1), this reached statistical significance at five minutes after application. The mean vessel diameter in this group continued to increase until 15 minutes, but it decreased slightly after that, though statistically insignificantly. The diameter changes of pulp vessel in the test group after the 5, 15, 30 and 60 minutes significantly differed from the control group. In the test group without etching prior to bonding (Figure 2), the vasodilatation reached statistical significance over the control group at 15, 30 and 60 minutes after application. There were no signs of stasis in the control or test conditions.

DISCUSSION

Most doubts concerning the use of dental adhesive systems are based on the possible biocompatibility problems of these materials (Stanley, 1994; White & others, 1994). Biological evaluations of composite materials have been controversial (Al-Dawood & Wennberg, 1993). To enhance bonding to the dentin, no lining or base materials were placed under the filling material, although material directly placed on the dentin could adversely influence the pulp, leading to changes in local circulation. Vasodilatation with the succeeding blood flow increase and the simultaneously increased tissue pressure may impair the hemodynamic state of the isolated pulp tissue, leading to pathological changes. Thus, the investigation of the vessel diameter in the dental pulp can be an important way of demonstrating the pathological effect of dental materials.

To enhance bonding with resin composite after acid etching, the primer, then the adhesive component is applied to the dentin, which plugs the tubules and prevents (Stanley, 1992; Nakabayashi, 1992) the penetration to the pulp of the toxic components of leachable unpolymerized monomers from the incomplete cured resin (Ruyter & Svendsen, 1978; Stanley, 1994). Dentinal etching prior to the applied bond materials and the resultant opening of dentinal tubule apertures increases the permeability of dentin (Stanley & others, 1975; Pashley & others, 1981). Thus, the toxic effect of the bonding system may be considerably more than the filling materials because they are initially applied directly on the etched dentin, thereby, potentially protecting the pulp from the subsequent effects of the composite filling material. For these reasons, blood flow reactions after applying a bonding system was investigated. The biocompatibility of the acid etching on the dental pulp has already been documented (Kanca, 1990; Stanley 1994; White & others, 1994).

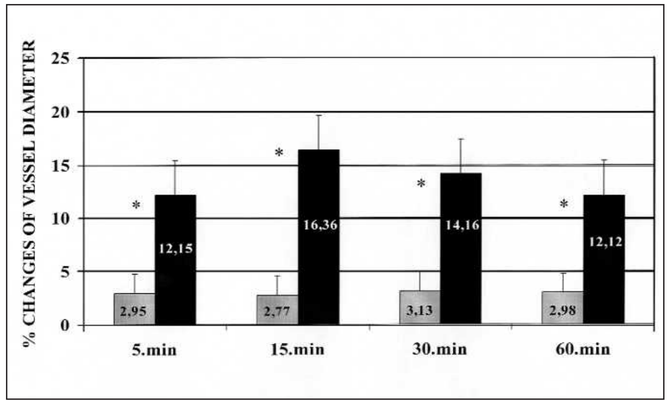

Figure 1. *Changes in vessel diameters of arterioles in rat dental pulp treated with etching prior to bonding (black bars=test group; n=10) or with saline (gray bars=control group; n=10). Each column represents a mean value (± SE) expressed as % changes of the baseline vessel diameter. Asterisks denote significant differences between test and control groups (p<0.05).*

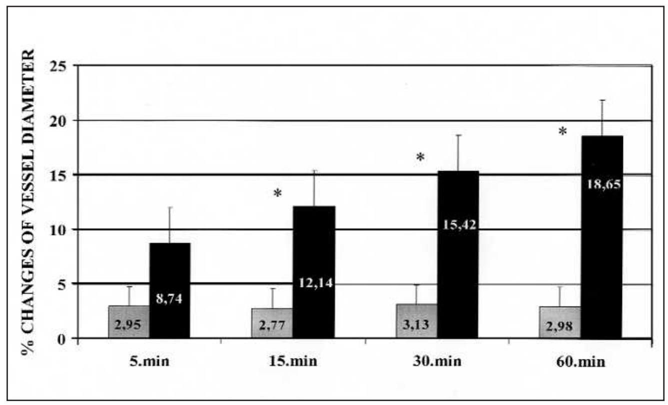

Figure 2. *Changes in vessel diameters of arterioles in rat dental pulp without etching prior to bonding (black bars=test group; n=10) or with saline (gray bars=control group; n=10). Each column represents a mean value (± SE) expressed as % changes of the baseline vessel diameter. Asterisks denote significant differences between test and control groups (p<0.05).*

Many authors have discussed the biocompatibility of bonding materials with contradictory conclusions. Previous studies (Brännström & Nyborg, 1971; Brännström & Nyborg, 1973; Bergenholtz & others, 1982; Cox & others, 1987; Quist, 1993; White & others, 1994) indicated that chemical toxic factors of restorative materials were less significant in causing pulpal injury than bacterial leakage around restoration margins. The disturbing effects of microleakage and bacterial contamination on the histopathological biocompatibility examination (Mjör, 1974; Bergenholtz & others, 1982; Felton & others, 1989; White & others, 1994) could be excluded by the present model, thus the observed acute changes in pulp circulation (compared to the control group) is the effect of the dental material used.

The model used in this study made it possible to avoid using zinc oxide-eugenol as a negative control (that is recommended in clinical usage tests), which could cause inflammatory reactions when placed within 0.5 mm of the pulp (Brännström & others, 1981; Cox & others, 1987; Kanca, 1990). For this reason vitalmicroscopic was used for this investigation.

The results of this study suggested that the primer and adhesive components of Scotchbond Multi-Purpose Dental Adhesive System (3M) showed acute vasodilating effects on the rat pulpal vessels, but this seemed to decrease within the time period of our experiment, for there was no sign of stasis or prestasis, indicating a possible reversible effect in noncarious healthy pulp tissues.

The comparison of the two test groups implied that acid etching of the dentin provoked more rapid pulpal reaction to the bonding agents. It was probably because of the opening effect of the dentinal etching on tubule apertures and the consequently increased dentin permeability. As a result, the bonding agents have facilitated diffusion through dentin to the pulp.

In this investigation, the observed arteriole was located in a deeper part of the pulp, where vessels contained regulating smooth muscle. This made it possible to postulate a mechanism by which bonding agents caused vasodilatation. When pulp is exposed to the bonding agents, intradental afferent nerves are stimulated, which in turn, release vasodilator agents (like SP and (GRP)(Gazelius & others, 1981). Because of the vasodilatation in the pulp, the rate of outward flow of fluid through the dentinal tubules increases (Matthews & Vongsavan, 1994). As a protective response then, the rate of diffusion of the irritating material from the tooth surface to the pulp would decrease. So the observed acute vasodilatory effect of the bonding materials in this study was not necessarily considered as a toxic reaction, for it could have been a physiological and pharmacological reaction (Heyeraas & Kvinnsland, 1992).

Caries and pulp alteration prior to using filling materials is a clinical finding that may escape the attention of researchers performing biocompatibility studies. The presence of pulpal enfeeblement caused by a chronic irritation of caries can adversely influence the toxic effect of the applied filling material. In addition, it has been recently shown that dentinal permeability associated with severe carious lesions was markedly higher compared to healthy dentin permeability (Hamid & Hume, 1995; Hume & Gerzina, 1996).

A cavity preparation 1 mm from the pulp will provoke an initial pulp lesion, leading to an acute inflammatory response (Stanley & Swerdlow, 1964; Stanley, 1994). Thus, in our experimental model, despite the cavity preparations being prepared with maximum protection to the pulp (Swerdlow & Stanley, 1959; Stanley, 1993), pulpal alterations were exhibited both in the control and test groups at the initial measurement because of the thin remaining dentin thickness (RDT). Due to the constant RDT (the observation was only possible at 20-40 µm RDT) and the uniformly-performed preparation (Stanley & Swerdlow, 1964), this change was standardized, so it might even be helpful in investigating whether the toxicity of the tested materials superimposed by the presence of pulpal enfeeblement prior to restoration (as stated earlier) was endurable for the dental pulp.

The model used in this study did not allow for chronic observations. However, this investigation still provided valuable information about the biocompatibility of the test material because the initial toxic effect of filling materials is greatest (Palasz & others, 1994; Hume & Gerzina, 1996; Hamid & Hume, 1996), and the pulpal toxicity of unpolymerized composite materials was relatively high. The results, presented in this study supplement the histopathological findings observed in investigations carried out under the ADA, FDI and ISO *in vivo* usage testing guidelines. However, future research is needed to determine the consequence of the observed vascular alteration in the dental pulp caused by the application of bonding agents.

CONCLUSIONS

The bond materials applied directly onto a very thin layer of dentin showed acute vasodilating effects on rat pulpal microvessels. However, no stasis or prestasis was detected, indicating a possible reversible reaction. There was no statistical difference between the extent of vasodilatation caused by the acetone containing and the acetone free bonding materials.

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Resistance to Condensation of "Condensable" Resin Composites as Evaluated by a Mechanical Test

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Clinical Relevance

Condensable resin composites are unlikely to facilitate restoration of acceptable proximal contacts in Class II restorations.

SUMMARY

This study compared the resistance-to-condensation forces of recently introduced condensable resin composites to that of amalgams and conventional resin composites. Using the flat platens of a servohydraulic testing machine, cylindrical specimens of each material 2.8 mm in diameter and 5.5 mm in length were compressed diametrally over two seconds to a thickness of 0.75 mm. Peak forces generated during compression were recorded.

This method ranked the various classes of restorative material for resistance to condensation in the same order as most clinicians subjectively reported, with the highest forces observed with admixed dental amalgams, followed in order by spherical amalgams, condensable resin composites and conventional resin composites. Although peak forces observed with the condensable resin composites were generally higher than those observed with conventional resin composites, these were significantly lower than the peak forces observed with amalgams.

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INTRODUCTION

The importance of the behavior of a restorative material during condensation has long been recognized. Deflecting a matrix band toward an adjacent tooth during condensation of Class II amalgam restorations, which promotes re-establishment of approximal contact, is usually described as resistance to condensation, or as plasticity. In blinded studies, experienced clinicians can detect minor differences in the plasticity of amalgam mixes (Mahler, 1967). They will select admixed amalgams over spherical amalgams as having more resistance to condensation and as more likely to facilitate adequate restoration of approximal contact (Brackett, Scheid & Wallace, 1990). However, relatively few efforts have been made to quantify this trait. The extant literature cites only indentation tests (Brackett & others, 1990; Mahler, 1967; Ogura, Hadavi & Asgar, 1983) of a relatively few amalgams. None of these tests has been placed into general use, and it is not known whether such indentation tests effectively predict clinical behavior over a larger spectrum of restorative materials.

Recently, manufacturers have introduced resin composites of stiff consistency, termed "condensable," and claim that these materials sufficiently resist condensation forces to facilitate re-establishment of approximal contacts of Class II restorations, a claim difficult to evaluate in the absence of an established quantitative method. This study evaluated the resistance-to-condensation forces of amalgams and resin composites using a servohydraulic testing machine.

METHODS AND MATERIALS

Representative conventional and condensable resin composites and spherical and admixed amalgams (Table 1) were evaluated for resistance to condensation through diametral compression of unset cylindrical specimens 2.8 mm in diameter and 5.5 mm in length of each material, using a servohydraulic testing machine (Model 8500; Instron Corp, Canton, MA 02021). Flat platens 10 mm in diameter were used to compress the specimens to a thickness of 0.75 mm over a period of two seconds. The peak force generated during compression was noted as an indication of the resistance of the material to condensation. Sample size was 10.

The specimens were formed via volumetric dispensing with an amalgam carrier. The reliability of this method was verified prior to testing by polymerizing resin specimens and allowing amalgam specimens to set. Weight comparisons showed variation of under 5% for specimens of the same material. For every specimen the compressed restorative material remained smaller in area than the platens of the testing machine. Amalgams were mixed according to the manufacturer's instructions, using a single-speed amalgamator (Capmix; ESPE Dental-Medizin GmbH, Seefeld D-82229, Germany). For all the selected amalgams, the regular set was tested. So that setting of the material would not affect the results of this test, amalgam specimens were compressed at an interval of 30 seconds after the conclusion of mixing. Resin specimens were formed and tested immediately, with half of the fluorescent tubes in the laboratory inactivated to lessen inadvertent light polymerization. Exposure of resin samples to this level of ambient lighting prior to beginning testing revealed no noticeable hardening, even over intervals much longer than the test.

Each data set was tested for normality using a D'Agostino Skewness test. Overall data were analyzed with a one-way ANOVA, followed by a Tukey-Kramer Multiple-Comparison Test.

RESULTS

The highest peak forces found with this method were in the admixed amalgams, followed in decreasing order by spherical amalgams, condensable resins and conventional resins (Figure 1, Table 2). Analysis of the data indicated that each of the eight data sets was of normal distribution (D'Agostino; $p>0.05$) and that there were significant differences among the tested groups (ANOVA; $p<0.05$). Average peak forces for all resins, including the condensable materials, were significantly lower than the lowest spherical amalgam group (Table 2). The test group means were not significantly different for materials within any of the four classes of restorative material evaluated in this study, except that the microfilled conventional resin composite was significantly

Table 1: *Restorative Materials (Type) and Manufacturers'*

Durafill VS (microfilled conventional composite resin) Heraeus Kulzer GmbH; Wehrheim D-61273, Germany
Z100 (conventional composite resin) 3M Dental Products, St Paul, MN 55144, USA
Solitaire (condensable composite resin) Heraeus Kulzer GmbH; Wehrheim D-61273, Germany
SureFil (condensable composite resin) Dentsply Caulk, Milford, DE 19963, USA
Megalloy (spherical amalgam) Dentsply Caulk, Milford, DE 19963, USA
Sybralloy (spherical amalgam) Kerr Corporation, Romulus, MI 48174, USA
Contour (admixed amalgam) Dentsply Caulk, Milford, DE 19963, USA
Disperalloy (admixed amalgam) Dentsply Caulk, Milford, DE 19963, USA

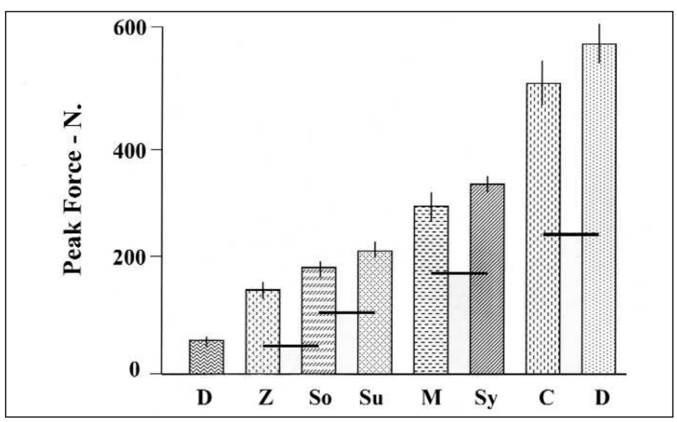

Figure 1. *Average peak forces (Newtons) for restorative materials under standardized compression. Groups not significantly different are connected by horizontal bars. (K = Durafill; Z = Z 100; So = Solitaire; Su = SureFil; M = Megalloy; Sy = Sybralloy; C = Contour; D = Dispersalloy)*

Table 2: *Peak Foces (Newtons) Generated During Compression of Restorative Materials*

	Mean (N)	SD	Tukey Grouping*
Durafill VS	44.1	3.0	A
Z100	155.0	28.3	B
Solitaire	184.9	17.8	BC
SureFIl	216.2	20.0	C
Megalloy	291.5	39.3	D
Sybralloy	334.6	28.8	D
Contour	557.5	70.7	E
Disperalloy	583.6	54.1	E

**means with the same Tukey grouping are not significantly different*

lower than the hybrid conventional resin composite. Average peak forces were significantly different for any comparison of materials of differing classes of restorative material, except that the hybrid conventional resin composite was not statistically different from one of the condensable resin composites (Figure 1, Table 2).

DISCUSSION

Virtually every clinician acknowledges the difficulty in restoring approximal contact in Class II resin composites. Various instruments and techniques have been advocated to displace the matrix toward an adjacent tooth, the most recent of which are recently introduced resins of a stiff consistency, termed "condensable." Using the term "condensation" in reference to manipulation of resins is inaccurate because no decrease in volume can be effected. However, the term has been used here since manufacturers routinely use it in promotional materials.

The peak forces observed in this study seem to be an effective predictor of resistance-to-condensation forces, or of the ability of a material to displace a matrix. Admixed and spherical amalgams rank in the same order as indicated by previous studies of blinded clinicians (Brackett & others, 1990), and condensable resins rank between the amalgams and conventional resins, as is frequently reported anecdotally by clinicians. The fact that similar materials tend to show no significant differences in mean peak force also lends credibility to this test, and the test has the further attribute that it can be effectively run on any servohydraulic testing machine since no special fixtures are required.

Given the results of this study, it is unlikely that resistance to condensation of condensable resin composites is comparable to any amalgam, but the newer resins are probably more effective in deflecting a matrix than are conventional resin composites. In making the specimens for this study, it was also observed that the condensable materials were less likely to stick to instruments than the conventional resin composites, again a separate but favorable trait in resin restorative materials.

CONCLUSIONS

Peak forces observed during compression of the two condensable resin composites were significantly lower than those of all four of the amalgams tested.

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Metal Surface Treatment: Characterization and Effect on Composite-to-Metal Bond Strength

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Clinical Relevance

The superior bond strength found using air-abrasion of metal with CoJet-Sand in combination with silane, may assist clinicians in providing greater long-term clinical success for resin bonded to metal restorative procedures.

SUMMARY

This study evaluated the effect of four methods of metal surface preparation and the use of silane on the bond strength between resin and a Noble metal alloy. SEM Examination and x-ray energy-dispersive spectroscopy (EDS) of the various metal surface treatments was also performed. One-hundred metal disks were cast in a Noble metal alloy (Porcelain #76). Ninety disks were polished flat and the surfaces received one of four abrasive treatments (n=20). 1) Roughening with a diamond bur at high speed; 2) Air abrasion with an intraoral sandblaster using alumina particles; 3) Air abrasion with KCP-2000 and 4) Air abrasion with an intraoral sandblaster using silanated silica covered alumina particles (CoJet-Sand). Half the specimens from each treatment group (n=10) were silanated prior to bonding procedures (All-Bond 2 adhesive system, Pertac-Hybrid composite). Specimens were stored in distilled water at 37°C and thermocycled prior to shear strength testing. The 10 remaining metal disks were used for scanning electron microscopy and x-ray energy-dispersive spectroscopy (EDS). Scanning electron microscopy examined the micromorphology of the metal surfaces produced by the four abrasive treatments and x-ray energy-dispersive spectroscopy (EDS) to evaluate changes in surface composition. Two untreated disks served as controls. One-way ANOVA and Tukey's HSD post-hoc test demonstrated that air abrasion with CoJet-Sand and silane resulted in significantly higher resin-to-metal bond strength than all other metal surface treatments, while roughening with a diamond bur produced the lowest bond strength. Resin-to-metal bond strength was similar for all other particle abrasive treatments with or without silane. Using silane significantly improved bond strength only for metal surfaces treated with CoJet-Sand. An increase in Al concentration was observed on metal surfaces sandblasted with aluminum oxide, and an increase in the concentration of both Al and Si was observed on surfaces air-abraded with CoJet-Sand.

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INTRODUCTION

Producing durable bonding of resin composite to metal is a desirable goal that has practical clinical application in dentistry. Achieving this objective could lead to the long-term success of such restorative procedures as resin composite repair-to-metal in porcelain fused-to-metal crowns and predictable retention of resin-bonded bridges or other metal restorations. Determining the ideal metal surface treatment to achieve reliable bonding of resin composite-to-metal however, remains a significant challenge (Albers, 1991; McConnell, 1993).

Several methods have been explored in an attempt to maximize adhesion of resin composite-to-metal. These methods can be classified as either micro or macro-mechanical, chemical or a combination of these (Czerw & others, 1995; Creugers, Welle & Vrighoef, 1988; Aquilino, Díaz-Arnold & Piotrowski, 1991; Kohli & others, 1990; Howe & Denehy, 1977). Micro-mechanical retention depends on creating surface defects in the metal surface by air abrasion with particles (sandblasting) or chemical etching that are subsequently infiltrated by resin and locked into place upon polymerization (Swift, 1989). Several studies have shown sandblasting or air abrasion to be an effective method of metal surface preparation for enhancing the bond of composite to metal (Czerw & others, 1995; Creugers & others, 1988). In addition, this method can be utilized in both intra- and extra-oral restorative procedures.

Two methods have been used to obtain chemical adhesion to metal. The first is done as a laboratory procedure and employs the use of an intermediate interface, such as tin plating or ceramic coating of the metal surface (Creugers & others, 1988; Gates & others, 1993). The second method involves using adhesive resin cements, such as Panavia, that contain a phosphoric acid moiety and methacrylate monomer group that adheres to the metal surface (Atta, Smith & Brown,1990; Smith & others, 1993). These resin cements are used in conjunction with air abrasion for cementation of crowns and resin-retained bridges.

Studies have shown that retention of composite to metal is further enhanced by using a silane coupling agent (Anagnostopoulos, Eliades & Palaghias, 1993; Scott, Strang & McCrosson, 1991). Silanes, more specifically their hydrolyzed analogues called silanols, are bifunctional molecules. The hydrophilic part forms hydrogen bonds with the surface bound water adsorbed on the alloy surface. The hydrophobic part of the silanol molecule copolymerizes with the methacrylate group of the resin via a covalent bond to enhance adhesion between metal and resin composite (Anusavice, 1996).

Micromechanical and chemical methods can be combined for increased retention. CoJet-Sand Intraoral System is an example which involves sandblasting with silanized silica-coated alumina particles that attach to the metal surface upon impact to form a ceramic-like film in a process referred to as "tribochemical coating." Thus, this system incorporates both the micro-mechanical retention produced by sandblasting with the interfacial chemical bonding produced from the silanated silica particles coating the metal surface. If these metal surface treatments work synergistically to provide superior resin-to-metal bonding, this would have important clinical implications.

This study evaluated the effect of four methods of metal surface preparation and the use of silane on the bond strength between resin and a Noble metal alloy. SEM Examination and x-ray energy-dispersive spectroscopy (EDS) of the various metal surface treatments was also performed.

METHODS AND MATERIALS

Shear Bond Strength

One-hundred metal disks, 8 mm in diameter and 1 mm thick were cast in a Noble metal alloy, Porcelain 76, consisting of 1.8% Au and 76% Pd. The remaining 21.6% consists of Cu, In, Ru and Ga in a proprietary combination (WE Mowrey, Co, St Paul, MN 55104). Ninety disks were embedded in Fastray, a polymethyl methacrylate resin in phenolic molds. The specimens were polished with 320 grit silicon carbide paper (Buehler, Lake Bluff, IL 60044) to remove methacrylate contaminants and to obtain a flat and uniform surface. The specimens were ultrasonically cleaned for three minutes and stored in deionized water for 24 hours before metal surface treatment and bonding procedures. The metal disks were randomly assigned to four experimental groups of 20 specimens. Each group received one of the following abrasive treatments:

Group 1: Roughening with a #253-SB medium-grit (85 mm) diamond bur (Premier Dental Products, King of Prussia, PA 19406) at high speed with copious water coolant.

Group 2: Air abrasion with an intraoral sandblaster (Microetcher, Danville Engineering, San Ramon, CA 94583) at 84 psi for four seconds using 50 µm alumina particles.

Group 3: Air abrasion with an intraroral cavity preparation system, (KCP-2000, American Dental Technologies Inc, Southfield, MI 48034) at 160 psi for four seconds using 27 µm alumina particles.

Group 4: Air abrasion with a tribochemical silica coating (CoJet-Sand Intraoral System, ESPE America, Norristown, PA 19404) at 34 psi for four seconds using 30µm silanated particles of silica coated alumina.

All abrasive treatments were performed perpendicular to the alloy surface from 5 mm distance.

After the abrasive treatments, half of the specimens of groups 1, 2 and 3 were rinsed with water spray and dried with an oil-free air syringe. Surfaces were cleaned with 32% H_3PO_4 (Uni-Etch, Bisco Inc, Itasca, IL 60193) for 15 seconds, then rinsed with water and dried with an oil-free air syringe. For group 4 (CoJet-Sand), surfaces were air dried immediately following the abrasive treatment as per manufacturer's instructions.

The surfaces of 10 specimens from each group were silanated with Porcelain Primer (Bisco, Inc); one coat was applied with a brush, let set for 30 seconds, then dried with an oil-free air syringe.

Subsequently, specimens in all groups received two coats of Primer A and B (Bisco, Inc) then were dried with an oil-free air syringe for six seconds to evaporate the solvent. A thin layer of Dentin/Enamel Bonding Resin (Bisco, Inc) was applied to the metal surface, then a split metal mold (4.3 mm in diameter and 2 mm in depth) was positioned and secured onto the specimen surface and the adhesive was polymerized for 20 seconds. A 2 mm increment of Pertac (ESPE America), a micro-hybrid resin composite, was placed in the mold and polymerized for 60 seconds using a visible curing light (Optilux 401, Kerr Corp, Orange, CA 92667), having an output intensity of at least 350 mW/cm_2. The split metal mold was separated and removed carefully so as not to disrupt the bond. Specimens were allowed to set for 30 minutes, then stored at 37°C for 48 hours prior to thermocycling for 300x between 5°C and 55°C. Shear bond strength was determined using a Zwick Materials Testing Machine (Zwick GmbH & Co, Ulm, Germany) using a knife-edge blade at a cross-head speed of 5 mm/minute. Data was analyzed using One-way ANOVA and Tukey's HSD post-hoc test.

Scanning Electron Microscopy and X-ray EDS Microanalysis

The remaining 10 metal disks were divided into five groups of two each and the surfaces treated according to the protocol previously described for groups 1 to 4. The additional group of two was left intact to serve as a baseline. The specimens were then secured onto an aluminum stub with conductive silver paint and secondary electron images were observed under a Hitachi S-4000 field-emission scanning electron microscope (Hitachi, Tokyo, Japan) at 100x, 1000x, 4000x and 10,000x magnifications to examine surface morphology. Area scan X-ray EDS microanalysis was rendered at 20 kV on the samples to determine the relative concentration of surface elements produced by the various surface treatments.

RESULTS

Shear Bond Strength

Mean shear bond strength data is presented in Table 1. One-way ANOVA revealed significant ($p<0.0001$) differences among groups. Tukey's HSD post-hoc test indicated that air abrasion with CoJet-Sand (ESPE) in combination with silane resulted in significantly higher resin-to-metal bond strengths than all other metal surface treatments, while roughening with a diamond bur produced the lowest bond strength. Particle abrasion of metal using CoJet-Sand w/o silane, or the KCP 2000 or microetcher with alumina with or w/o silane resulted in similar bond strengths. The use of silane produced higher bond strength only when used in conjunction with CoJet-Sand ($p<0.0001$).

Table 1: *Shear Bond Strength of Resin to Metal (MPa)*

Surface Treatments	n	Mean ± S.D	Tukey's HSD				
CoJet Sand/Silane	10	13.5 ± 2.7	A				
CoJet Sand/ESPE-Sil	10	9.7 ± 1.5		B			
CoJet Sand	10	6.4 ± 1.3			C		
KCP-2000	10	6.4 ± 1.2			C		
KCP-2000/Silane	10	5.8 ± 1.2			C		
Micro-etcher	10	5.1 ± 0.6			C	D	
Micro-etcher /Silane	10	4.9 ± 2.1			C	D	
Diamond/Silane	10	3.5 ± 1.0				D	E
Diamond	10	2.9 ± 0.7					E

Mean values with the same letter are not significantly different ($\propto = 0.05$)

The debonded surfaces of all specimens were observed under 20x magnification to evaluate the mode of failure. Even though bond strengths for CoJet Sand/silane groups were higher than for other groups, it appeared that all specimens failed at the joint interface between the adhesive resin and metal. This agrees with previous investigators (Kern and Thompson, 1993; Hanson and Moberg, 1993). Since light microscopy was utilized, it was impossible to discriminate in which intermediate layer; silane, Primer A &B or unfilled adhesive resin, the predominate mode of failure occurred.

Scanning Electron Microscopy and X-ray EDS Microanalysis

The micro-morphological changes occurring in the surface of the metal specimens as a result of the various surface treatments were analyzed using SEM and x-ray EDS microanalysis was used to determine compositional changes (Figure 1).

SEM revealed differences in surface morphology among groups. Representative samples from all the treatments are shown in Figures 2 through 5. Roughening with the diamond bur resulted in a regular linear groove-like pattern in the metal surface (Figure 2). Sandblasting with 50 µm alumina particles using the Micro-etcher and with 27 µm alumina using the KCP-2000 resulted in comparable surface morphology,

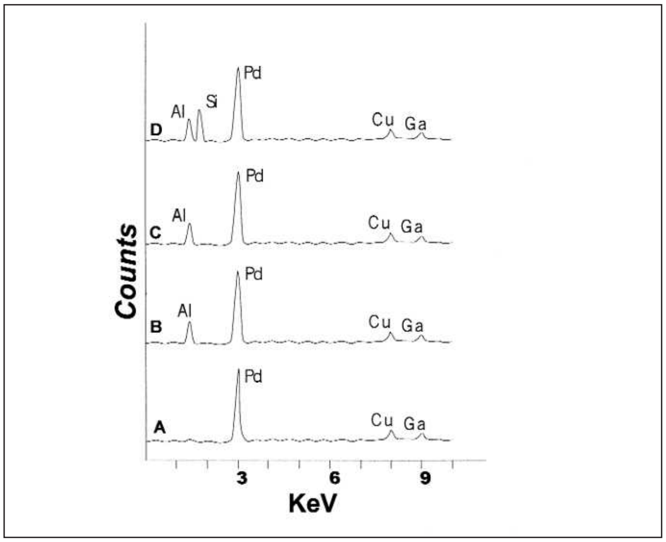


Figure 1. *X-ray EDS spectra of treated surfaces. A: Diamond, B: Microetcher, C: KCP-2000, D: CoJet-Sand.*

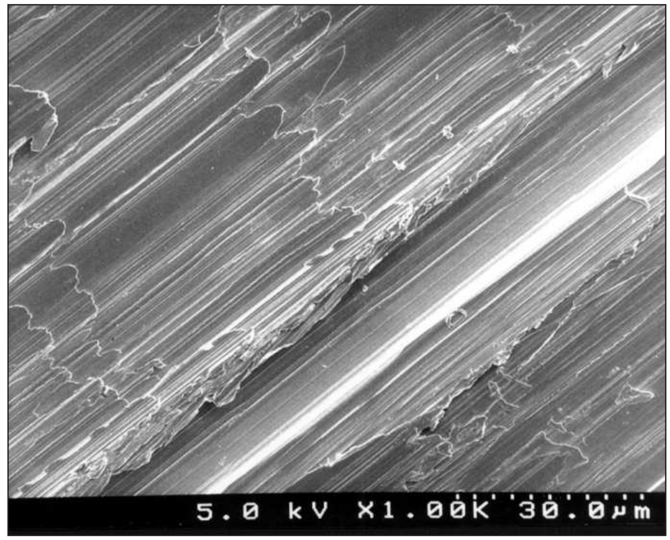
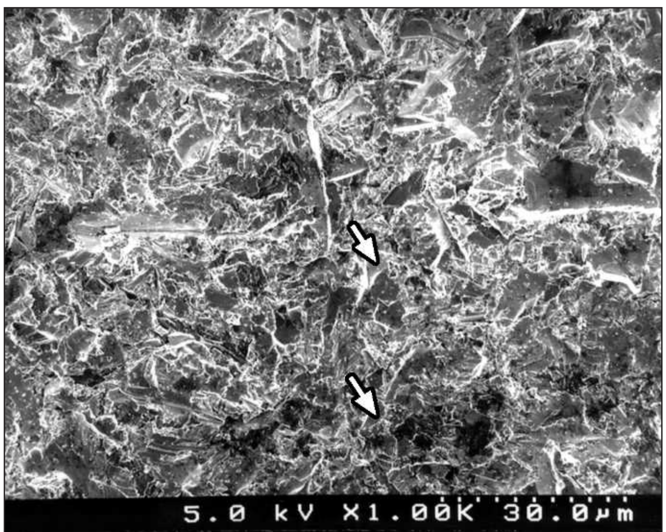


Figure 2. *Metal surface roughened with a diamond bur.*



exhibiting an irregular surface pattern. In addition, particles appear to be embedded in the metal surface for these groups, which are assumed to be alumina (Figures 3 and 4). Sandblasting with CoJet-Sand appeared to produce smaller irregularities in the metal surface compared to other methods of sandblasting. Two types of particles appear to cover the roughened metal surface, presumably silica and alumina (Figure 5).

SEM micrographs were taken of the alumina and CoJet-Sand particles at different magnifications. CoJet-Sand particles consist of a layer of small particles covering the larger alumina particles, which the manufacturer claims to be silica (Figure 6). This is in contrast to the alumina particles of the Microetcher (Figure 7) and KCP-2000, which exhibited a smoother surface.

In order to confirm the source of the silica, x-ray EDS microanalysis and elemental mapping for alumina and silica were performed on the alumina and

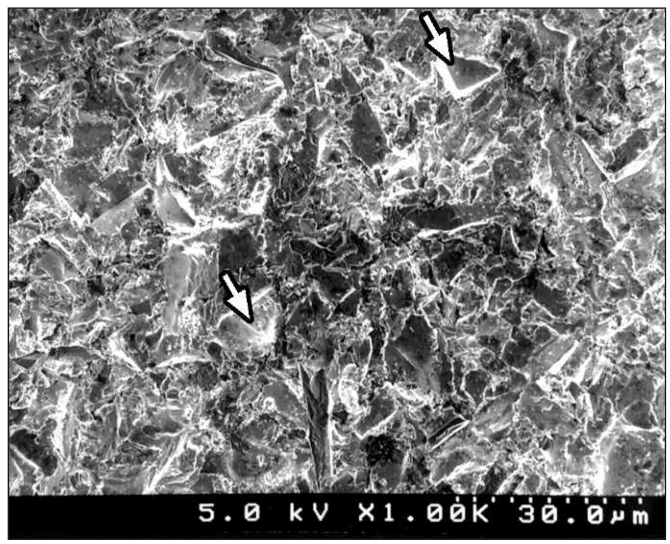


Figure 4. *Metal surface sandblasted with 27 µm alumina particles using the KCP-2000.*

CoJet-Sand particles. The x-ray EDS Spectra of the alumina and CoJet-Sand particles can be seen in Figure 8. Silica was only detected on the CoJet-Sand particles.

Representative area scan X-ray EDS spectra of the treated surfaces are shown in Figure 1. EDS X-ray microanalysis revealed an increased concentration of alumina on metal surfaces treated with KCP-2000 (12.8%), the Micro-etcher (11.3%) and CoJet-Sand (14.2%) (Table 2). An increase in the concentration of silica (12.9%) was found only in specimens treated with CoJet-Sand (Table 2).

DISCUSSION

This study compared the bond strength of a resin com-

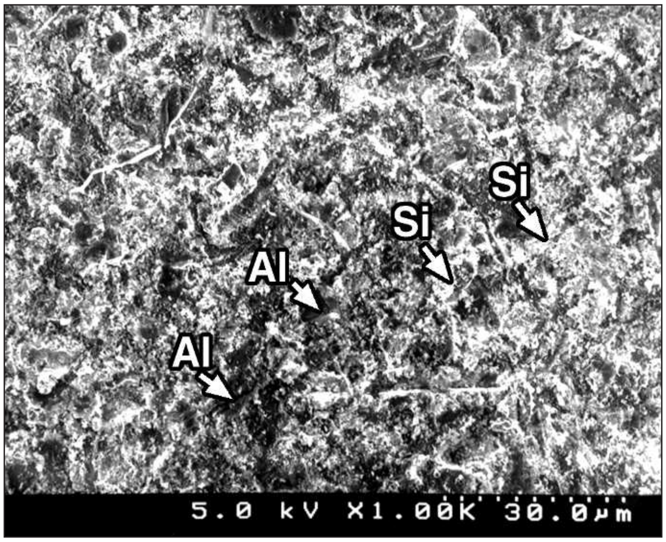


Figure 5. *Metal surface sandblasted with CoJet-Sand using the Microetcher.*

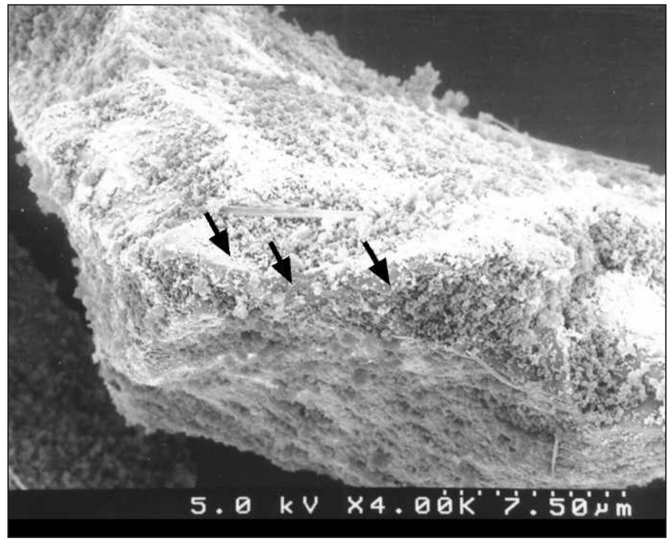


Figure 6. *CoJet-Sand particles consist of a layer of small silica particles covering the larger alumina particles.*

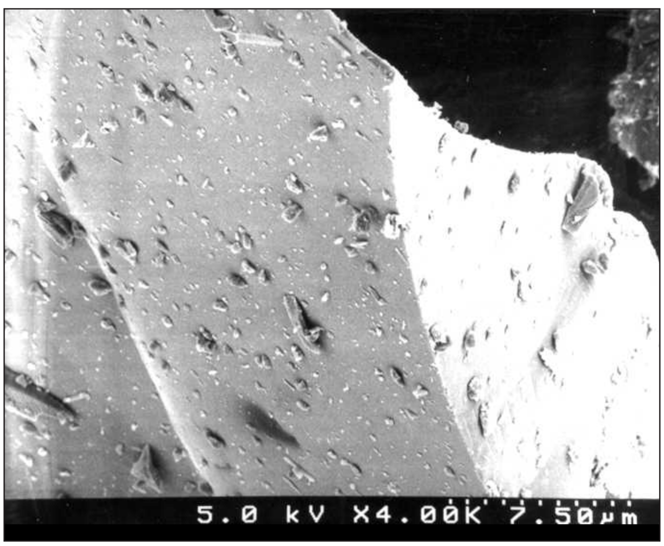


Figure 7. *Alumina particles of the Microetcher and KCP-2000 which had a smoother surface.*

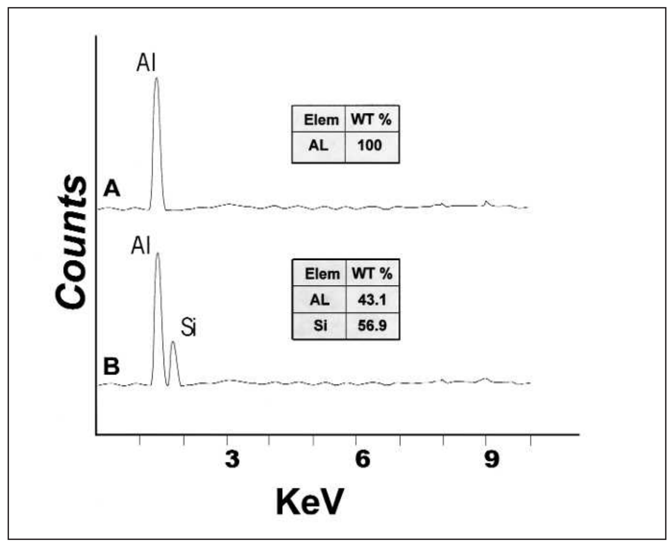


Figure 8. *X-ray EDS spectra of alumina and CoJet-Sand particles. A: Alumina, B: CoJet Sand.*

posite to cast metal using traditional methods of surface roughening as well as a new product, CoJet-Sand Intraoral. The products and procedures tested in this *in vitro* study simulate typical *in vivo* procedures for repair of restorations that have fractured but are still repairable in the mouth, including the use of silane.

Under this study's conditions, sandblasting the metal surface prior to bonding procedures with CoJet-Sand and silane provided superior bond strength of resin-to-metal when compared to other methods of surface preparation. Using silane enhanced the bond strength only for this method of surface roughening. Overall, bond strength values in this study were low compared to those found in other studies. (Atta & others, 1990; Czerw & others, 1995; Swift, 1989). Generally, resin-to-metal bond strengths should be around 20 MPa if the shear force is distributed evenly. The fact that a knife edge blade was used on the composite button may have caused high stress concentrations at the top of the sample, thus artificially lowering the values determined by the Zwick.

X-ray EDS microanalysis of the metal surface composition revealed a significant increase of silica in those specimens treated with CoJet-Sand (Figure 1). This agrees with other authors who found that a layer of small silica particles remained on the metal surface following tribochemical silica-coating, increasing the silica content from 12-20% (Kern & Thompson, 1993).

After sandblasting with CoJet-Sand, a silane is added to wet the surface and form a chemical bond between the silica layer and the resin composite.

Table 2: *Elemental Composition of Treated Surfaces From EDS X-Ray Microanalysis (WT%)*

Surface treatment	Pd	Cu	Ga	Al	Si
Diamond	78.1	12.3	9.5	0	0
Microetcher	69.9	10.8	7.8	11.3	0
KCP-2000	68.8	10.8	7.9	12.8	0
CoJet Sand	58.9	8.3	5.6	14.2	12.9

Results of previous studies suggest that silica-coating of non-precious alloys, followed by using silane, significantly improves chemo-mechanical bonding of resin-to-metal (Smith & others, 1993; Anagnostopoulos & others, 1993). The higher bond strengths achieved with CoJet-Sand in the current study support these findings.

The improved adhesion obtained using CoJet-Sand in combination with a silane compared to the same treatment without silane suggest that the embedded silica particles are beneficial in the system only when a silane is used. Thus it appears that silane is necessary to enhance the adhesion of the resin in the composite to the silica particles.

The role of silane in metal surface treatment has been studied. Initially, silanes protect the metal surface from contamination prior to bonding procedures. Silanes have been advocated for use in promoting adhesion of resin-to-metal through various mechanisms. The main reason why resin adhesives fail to obtain good contact quality with metal surface is not due to high viscosity, but the fact they must compete with absorbed water on the metal surface. Dental silanes improve metal surface wetting from resin materials by bonding to the absorbed water and acidic oxides on the metal surface and to the methacrylate groups on the resin adhesive. This facilitates the penetration and interlocking of resin into the roughened surface (having increased surface area and energy) created by air abrasion. Since the cohesive strength of a set silane layer is low, by itself it cannot create the necessary retentive strength to metal. Instead, silane provides a coating over which the adhesive resin can readily flow to attain intimate contact and subsequent micromechanical retention to the sandblasted metal surface. No significant improvement in bond strength, however, was found in this study with the use of silanes, except when the surface was sandblasted with silica containing CoJet-Sand.

Although variation in surface morphology was observed for those surface treatments incorporating sandblasting at various pressures and particle sizes, no difference in bond strength was found. This suggests that within the range used in this study, particle size and pressure may not be an important factor in determining adequate metal surface roughness. Nevertheless, consistent sandblasting produced higher bond strengths compared to roughening with a diamond bur, which produced a characteristic linear groove pattern as observed under the SEM (Figure 2).

Sandblasting with alumina alone resulted in an increased concentration of alumina on the metal surface, as documented by x-ray EDS Microanalysis (Figure 1), in addition to the micromechanical roughening (Figures 3 and 4). This agrees with other investigators (Díaz-Arnold & others, 1996; Kern & Thompson, 1993). It is reasonable to assume that these alumina particles were embedded in the metal surface since 32% phosphoric acid was used to remove loose debris prior to x-ray analysis. The role of these alumina particles in resin-to-metal adhesion remains unknown. It may be that chemically active phosphate esters and methacrylate monomers in adhesive systems, such as Panavia 21, when applied to the sandblasted surface, bond directly to the embedded alumina particles, thus enhancing adhesion of resin-to-metal (Coelho & others, 1996; Yoshida & others, 1993). Other researchers have suggested that the alumina oxide particles covering the oxide surface of the metal may in fact contribute to the long term adhesive failures of the resin-to-metal bond due to bond degradation from long-term water exposure (Díaz-Arnold & others, 1996; Kern & Thompson, 1993).

It is important that future studies evaluate the long-term effect of thermal, mechanical and water storage on the stability of the resin-to-metal bond. Kern and Thompson (1994) evaluated the effect of thermal cycling and water storage on the bond strength of composite to metal. They recommended using 1500 cycles to thermally stress the bond. Following silica coating, bond strength increased after 30 days but decreased after 150 days, whereas sandblasting alone resulted in a steady decrease in the bond strength over time. It has been suggested that water uptake by the resin at the interface causes hydrolysis of the silane bonds with a resultant deterioration in the adhesion between resin and metal. This may explain the degradation of the bond found with long term water exposure. This study used 300 cycles and did not evaluate the effect of long-term water storage on bond strength.

The superior bond strength achieved from treating the metal surface with CoJet-Sand and silane prior to bonding procedures has several clinical implications. This system can be used both intraorally and extraorally. Intraorally, it is indicated for the repair of fractured fixed porcelain fused-to-metal restorations where metal has been exposed and extraorally for procedures, such as preparing the metal surfaces of cast appliances prior to cementation.

CONCLUSIONS

In this study superior bond strength was found using air-abrasion of a semi-precious metal alloy with CoJet-Sand in combination with silane, compared to surface preparation with a diamond bur or air abrasion with aluminum oxide particles or KCP 2000. This information may assist clinicians in providing greater long-term clinical success for resin bonded to metal restorative procedures.

Acknowledgments

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Solubility and Sorption of Resin-Based Luting Cements

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K McMillen • N Clelland

Clinical Relevance

Hygroscopic expansion and deterioration of luting cements can result from the marginal discrepancy of restorations. Previous studies have shown that hygroscopic expansion of resin-modified glass-ionomer cements occur as a result of water sorption (Kanchanavasita, Anstice & Pearson, 1997). This expansion may initially compensate for polymerization shrinkage; however, some concern has been raised regarding the forces produced against the tooth and restoration as a result of hygroscopic expansion (Momoi & McCabe, 1994). Clinical concern regarding the solubility of luting cements revolves around the deterioration of a luting cement, which may result in breakdown of the material and potential recurrent decay followed by failure of the restoration. In this study, all resin-modified glass-ionomer cements showed significantly higher water sorption and lactic acid solubility compared to composite cements.

SUMMARY

This study compared the seven-day water sorption, water solubility and lactic acid solubility of three composite cements and three resin-modified glass-ionomer cements. Disc-shaped specimens measuring 15 mm x 0.5 mm were prepared according to each manufacturer's specifications and desiccated to a constant mass. Specimens were then placed in distilled water at 37°C for seven days. Acid solubility was performed in 0.01 M lactic acid. The weight changes of the specimens after immersion in distilled water or 0.01 M lactic acid were measured using an electronic analytical balance. A one-way ANOVA followed by the Ryan-Einot-Gabriel-Welsch (REGW) multiple range test was performed on all data. Significant differences (*p*<0.05) were found among several cements tested for each of the properties investigated. Due to their hydrophilic nature, all resin-modified glass-ionomer cements showed significantly higher water sorption compared to composite cements.

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INTRODUCTION

Solubility and sorption are important properties in assessing the clinical durability of luting cements. Consequently, the sorption and solubility of luting cements has been extensively evaluated both *in vivo* and *in vitro* (Pluim & others, 1984; Setchell, Teo &

Khun, 1985; Um & Oilo, 1992; Kanchanavasita, Anstice & Pearson, 1997; Yoshida, Tanagawa & Atsuta, 1998). Clinically, solubility and sorption may cause degradation of the cement, leading to debonding of the restoration and potential recurrent decay (Yoshida, Tanagawa & Atsuta, 1998).

Table 1: *Cements Tested*

Cement	Manufacturer	Type	Curing Method
Panavia 21	J Morita, Tustin, CA 92780	Composite	Polymerization reaction
Enforce	LD Caulk, Milford, DE 19963	Composite	Polymerization reaction (dual-cure)
Resiment	Septodont, New Castle DE 19720	Composite	Polymerization reaction (dual-cure)
Vitremer Luting	3M, St Paul, MN 92614	Resin-modified glass ionomer	Polymerization and acid-base reaction
Advance	LD Caulk, Milford, DE 19963	Resin-modified glass ionomer	Polymerization and acid-base reaction
Fuji Duet	GC America, Chicago IL 60803	Resin-modified glass ionomer	Polymerization and acid-base reaction

The sorption of water by a material may have clinically beneficial consequences by compensating for initial polymerization shrinkage, yet damaging through hygroscopic expansion, which could cause internal stresses and degradation (Bowen, Rapson & Dickson, 1982; Ferracane, Antonio & Matsumoto, 1987; Kanchanavasita, Anstice & Pearson, 1997). Some studies (Feilzer & others, 1995; Kim, Hirano & Hirasawa, 1998), have identified hygroscopic expansion of a material resulting from the absorption of as a factor for improved marginal adaptation, while others have noted more detrimental effects such as filler/matrix debonding and breakdown of the resin matrix and restoration fracture (Calais & Soderholm, 1988; Kalachandra, 1989; Leevailoj & others, 1998).

Solubility measures the resistance of a material to disintegration and dissolution in some appropriate *in vitro* test medium or *in vivo* (Yoshida, Tanagawa & Atsuta, 1998). Such solubility can cause deterioration that affects the marginal integrity of a restoration, resulting in potential recurrent decay (Hersek & Canay, 1996). The standard laboratory test for solubility of resin-based materials is the American National Standards Institute American Dental Association (ANSI/ADA) specification #27, which uses a disk of the set material suspended in water for seven days (American Dental Association, 1988). This test has been criticized because acid-producing bacteria found in the oral cavity, lactobacilli and Streptococcus mutans, also affect the solubility of luting cements (Mesu & Reedijk, 1983; Yoshida, Tanagawa & Atsuta, 1998). To account for the acidic environment of the oral cavity, the Jet-Test method for solubility was utilized by some investigators (Setchell, Teo & Khun, 1985;). A subsequent modification of the Jet-Test method was developed to address the concern that the mechanical erosion of the original Jet-Test method does not occur in all cement types (Yoshida, Tanagawa & Atsuta, 1998).

Conventional glass-ionomer luting agents have been used due to their beneficial clinical properties, such as physicochemical bonding to tooth structure (Lacefield & others, 1985), fluoride ion release (Swartz & others, 1984) and a low coefficient of thermal expansion (McLean & Gasser, 1985). However, these cements are also susceptible to brittle fracture, wear and dissolution in an aqueous environment (McLean & Wilson, 1977). To improve these deficiencies, introducing resin-modified glass-ionomer cements has expanded the choices available to the clinician. The modification of the conventional glass-ionomer chemistry with the addition of polymerizable monomers such as 2-hydroxyethyl methacrylate (HEMA) and a photoinitiator (camphoroquinone) has produced materials with an improved setting reaction due to visible light irradiation (Um & Oilo, 1992). It has been shown that the light curing decreases the water-sensitivity of these cements when compared to the conventional glass-ionomer cements that use an acid-base setting reaction (Eliades & Palaghias, 1993; Cho, Kopel & White, 1995). The resin-modified glass-ionomer cements possess the benefits of the conventional glass-ionomer cements, such as fluoride release and adhesion to tooth structure, along with the benefits of the composite materials, such as improved strength, water sorption and solubility (Wilson & others, 1989; Kovarik & Muncy 1995).

Resin-based cements have become popular in clinical practice and are the preferred luting agent for porcelain veneers, all-ceramic crowns and, more recently, indirect composite resin restorations. In addition, less microleakage has been observed for the resin-based luting cements when compared to conventional luting cements, suggesting potential increased long-term clinical durability (White & others, 1992; Tjan, Dunn & Grant, 1992; Yoshida Tanagawa & Atsuta, 1998). This investigation compared the water sorption, water solubility and lactic acid solubility of three composite cements and three resin-modified glass-ionomer cements.

METHODS AND MATERIALS

Product and manufacturer information for the six cements tested is listed in Table 1. Three composite cements were evaluated: Panavia 21, a Bis-GMA-based resin cement containing the adhesive monomer methylacryloxydecyldihydrogenphosphate, and Enforce and Resiment, which are also Bis-GMA-based but do not contain any adhesive chemicals. Three resin-modified glass-ionomer cements were also studied: Vitremer Luting, Advance and Fuji Duet. Manufacturers' specifications for proper mixing time, paste-to-paste and powder-to-liquid ratio and exposure times were carefully followed. The Enforce and Resiment composite specimens were light cured utilizing an 80-second exposure time. Methods of testing followed ANSI/ADA specification #27 for resin-based filling materials. The methodology, outlined in the remainder of this section, followed the testing recommendations of ANSI/ADA specification #27.

Water Sorption and Solubility

Water sorption and solubility were measured at seven days. Four disc-shaped specimens measuring 15 mm in diameter by 0.5 mm in thickness were prepared for each cement type, utilizing polypropylene molds that were compressed between two glass plates under a constant load (5 kg). Statistical analysis of pilot experiments indicated that a sample size of four specimens in each experimental group would be adequate because of the low coefficient of variation. After bench curing for 10 minutes, specimens were removed from the mold and placed in a 37° + 2°C oven for 24 hours to insure a complete set. The diameter and thickness of each specimen was measured three times utilizing a digital micrometer (Mitutoyo Digimatic, Model CD-6 BS, Mitutoyo Corporation, Japan). Specimens were then placed in a desiccator at 37° + 2°C for 24 hours. Specimens were then transferred to a second desiccator at 23° + 2°C for one hour and weighed using an electronic analytical balance (Model AE 240, Mettler-Toledo, Inc, Toledo, OH). This cycle was repeated until a constant initial mass (m_1) for testing was obtained. A constant mass was determined when the mass loss of each specimen was not more than 0.2 mg in a 24-hour period. The specimens were then immersed in distilled water at 37°C + 2°C for seven days, after which they were removed, washed with distilled water, blotted dry and air dried for 15 seconds. The specimens' weight was again recorded within one minute of removal from the water (m_2). The discs were redesiccated at 37°C, followed by 23°C, for the same time periods as previously described at these two temperatures, and weighed until a constant mass (m_3) was obtained.

The volume (V) of each specimen was calculated in cubic millimeters by measuring the diameter and the thickness of the specimen at the center and at four equally spaced points on the circumference. The values for water sorption (wso) and solubility (wsl) were calculated using the following equations (American Dental Association, 1988):

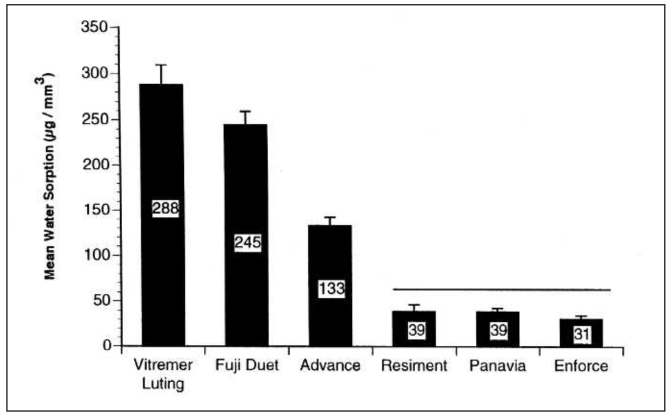

Figure 1. *Mean water sorption in µg / mm3 for the dental cements tested. Groups connected by a horizontal line are not significantly different (µ=0.05).*

$$w_{so} = \frac{m_2 - m_3}{V}$$

$$w_{sl} = \frac{m_1 - m_3}{V}$$

where m_1 = conditioned mass of the specimen in micrograms prior to immersion in solution, m_2 = mass of the specimen in micrograms after immersion in solution, m_3 = reconditioned mass of the specimen in micrograms after immersion in solution and V = volume of the specimen in cubic millimeters.

Lactic Acid Solubility

Acid solubility was also measured by immersion of the specimens in 0.01 M lactic acid (pH = 4.0), using the foregoing technique and calculations. ANSI/ADA specification #27 does not include testing recommendations for acid solubility; therefore, the technique recommended by previous investigators was followed (Kent, Lewis & Wilson, 1973; Yoshida, Tanagawa & Atsuta, 1998). The pH of 4.0 was utilized because this is the lowest pH found in plaque (Beech and Bandyopadhyay, 1983).

RESULTS

A one-way ANOVA followed by the Ryan-Einot-Gabriel-Welsch (REGW) multiple range test was performed on all data. The ANOVA (p<0.001) and REGW multiple range test (p<0.05) results indicated significant differences between several of the cements tested for each of the properties investigated.

The results of the water sorption testing are presented in Figure 1 and Table 2. Vitremer Luting, a resin-modified glass-ionomer cement, exhibited a seven-day mean water sorption of 288 micrograms per cubic millimeter, which was significantly higher than any of the

Table 2: *Mean Water Sorption, Water Solubility, Lactic Acid Solubility in µg/mm³ and Standard Deviations (SD) For Cements Tested*

Cement	Water Sorption (SD)	Water Solubility (SD)	Lactic Acid Solubilitly (SD
Vitremer Luting	287.6 (21.1)	13.9 (5.4)	139.8 (3.5)
Fuji Duet	244.8 (14.5)	38.4 (3.4)	108.3 (7.7)
Advance	133.0 (9.5)	29.8 (2.0)	83.9 (4.6)
Resiment	39.4 (7.9)	7.1 (1.5)	13.3 (6.0)
Panavia	39.2 (2.5)	24.3 (2.2)	18.2 (0.5)
Enforce	31.4 (1.3)	7.8 (1.1)	9.8 (2.0)

other cements tested. In addition, the water sorption of Vitremer Luting was nearly nine times that of the three composite cements. No significant difference was found between Panavia, Enforce and Resiment—the composite cements tested—which had mean water sorption values between 30 and 40 micrograms per cubic millimeter.

The water solubility testing results are presented in Figure 2. Fuji Duet, a resin-modified glass ionomer, exhibited a mean seven-day water solubility significantly higher than any of the other cements tested. Vitremer Luting exhibited significantly less water solubility, when compared to Fuji Duet, Advance or Panavia, which were all significantly different from each other. No significant difference in water solubility was found between Resiment and Enforce.

The results of the lactic acid solubility are presented in Figure 3. Vitremer Luting exhibited a 24-hour lactic acid solubility, which was significantly greater than any of the other cements tested. The resin-modified glass-ionomer cements (Vitremer Luting, Fuji Duet and Advance) exhibited significantly higher lactic acid solubility when compared to the composite cements. No significant difference was noted between the composite cements Panavia, Resiment and Enforce.

DISCUSSION

The methodology for sorption/solubility utilized in this study followed ANSI/ADA specification #27 for resin-based filling materials. The specification requires that the specimens first be placed in a desiccator after 10 minutes of bench curing and removal from the polypropylene mold. A recent study suggested a modification to the specification, where the specimens would be immediately placed in solution after preparation and not desiccated first (Kanchanavasita, Anstice & Pearson, 1997). The rationale behind this modification is that water is a requirement for the setting reaction of the resin-modified glass-ionomer cements and that initial desiccation of the specimens could remove water essential for the setting reaction. In this study, ANSI/ADA specification #27 was modified by waiting 24 hours before placing the specimens in the desiccator to insure complete set of each material. It was felt that desiccation of the specimens immediately after fabrication could possibly affect the solubility and sorption results due to an incomplete glass-ionomer set.

The resin-modified glass-ionomer cements tested in this study exhibited significantly higher water sorption compared to the composite cements. Clinical implications of this finding are that increased water sorption of the resin-modified glass-ionomer cements may result in hygroscopic expansion, which could lead to significant outward force against both tooth structure and the restoration. Moreover, HEMA, a significant monomer component of the resin-modified glass-ionomer cements, is also often used in the preparation of hydrogels (Yap & Lee, 1997). Hydrogels are water-based polymers which can imbibe further water and undergo substantial swelling, which has been referred to as the hydrogel effect. As a result of the hydrogel effect, hygroscopic expansion can occur. Hygroscopic expansion has been shown to occur with microfil composite materials that only exhibit 2-4 % water sorption, whereas the resin-modified glass-ionomer cements tested in this study exhibited between 8% and 14% water sorption by weight (Momoi & McCabe, 1994). While the initial effects of hygroscopic expansion may

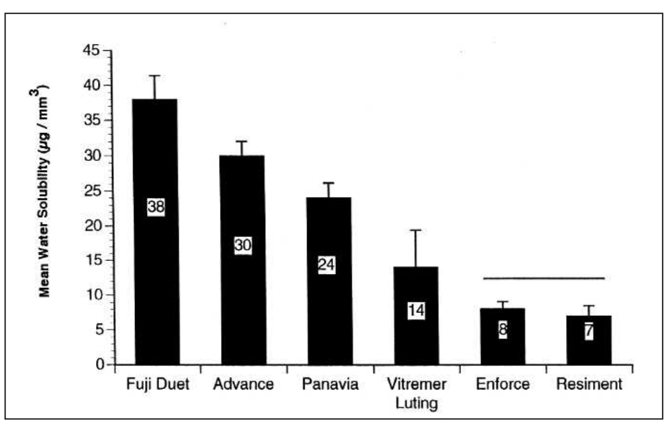

Figure 2. *Mean water solubility in µg / mm_3 for the dental cements tested. Groups connected by a horizontal line are not significantly different (µ=0.05).*

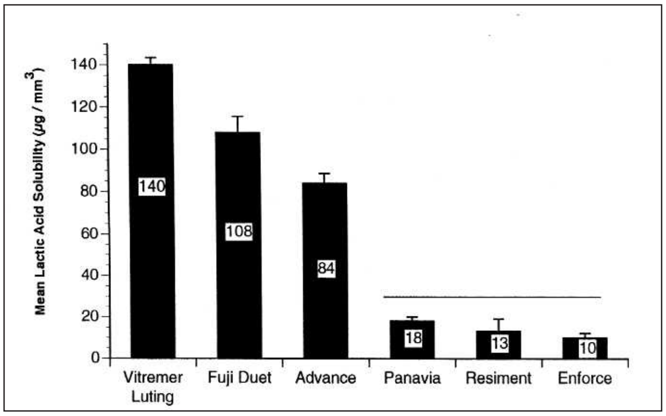

Figure 3. *Mean lactic acid solubility in μg / mm_3 for the dental cements tested. Groups connected by a horizontal line are not significantly different (μ=0.05).*

be beneficial by compensating for polymerization shrinkage, one study has shown that the expansion and positive pressure due to water sorption continued to increase over a period of six months, suggesting some cause for clinical concern (Momoi & McCabe, 1994). Examples of all-ceramic crown fracture have been shown in the literature, which may have been attributed to the hydrogel effect of resin-modified glass-ionomer cements (Leevailoj & others, 1998). Using resin-modified glass-ionomer cements for the cementation of all-ceramic crowns remains questionable.

Vitremer Luting exhibited significantly less water solubility when compared to Fuji Duet or Advance. Low phase separation during the setting reaction between the Vitremer Luting glass ionomer matrix and the polymerizable methacrylate groups on the polycarboxylic acid chain might account for the decreased water solubility of Vitremer Luting. This is because the free radical polymerizable groups are attached to the polycarboxylic acid chain, which decreases the likelihood of unpolymerized free monomer being leached out in an aqueous environment. Subsequently, the hydrophilic nature of Fuji Duet and Advance may have resulted in significantly higher water solubility, when compared to the composite cements (Iwami & others, 1998, Yap & Lee, 1997).

The resin-modified glass ionomers exhibited significantly higher lactic acid solubility when compared to the composite cements. Although the solubility of the resin-modified glass ionomers was inferior to the composite cements, clinical studies have shown that the glass-ionomer cements have exhibited improved solubility compared to zinc phosphate and polycarboxylate cements (Hersek & Senay 1996). This improvement in solubility is credited to the setting reaction between the fluoroaluminosilicate glass and the polyacrylic acid (Crisp & Wilson 1974; Um & Oilo 1992).

Vitremer Luting exhibited significantly higher lactic acid solubility when compared to Fuji Duet, Advance and the composite cements. However, the mean water solubility of Vitremer Luting was significantly lower when compared to Fuji Duet, Advance and Panavia. The clinical significance of the information obtained from the standard laboratory test for solubility that utilizes distilled water as a media has been criticized by some investigators (Beech & Bandyopadhyay 1983; Wilson 1976). One reason this test has been criticized is because acid-producing bacteria found in the oral cavity, lactobacilli and Streptococcus mutans, also affect the solubility of luting cements (Mesu & Reedijk, 1983; Yoshida, Tanagawa & Atsuta, 1998). Therefore, a test which utilized an acidic media was suggested by some investigators (Setchell, Teo & Khun, 1985;). In addition, the clinical findings for solubility of dental cements have been quite different than the results of water solubility testing *in vitro*. For example, despite the variety of techniques used in clinical testing, the rankings obtained for the various cements is in excellent agreement (Beech & Bandyopadhyay 1983). When comparing the clinical rankings to *in vitro* water solubility results, a poor correlation was observed (Mitchem & Gronas 1978; Richter & Ueno 1975; Osborne et al 1978; Wilson 1976; Beech & Bandyopadhyay 1983). Subsequently, rankings obtained from lactic acid solubility testing were in better agreement with the clinical rankings (Beech & Bandyopadhyay 1983). It appears that lactic acid solubility may provide information more clinically relevant than water solubility.

Clinically, susceptibility to moisture contamination has also been reported as a disadvantage of conventional glass-ionomer cements (van de Voorde, Gerdts & Murchison, 1988). Early water contact affects the setting reaction of glass-ionomer cements more significantly than for composite cements, because water is absorbed due to the elution of the cement-forming cations (Um & Oilo, 1992). With the increasing development of the cement structure as the setting reaction continues, there is decreased water penetration (Mesu, 1981). The resin-modified glass-ionomer cements undergo both a glass-ionomer (acid-base) setting reaction and a composite (polymerization) setting reaction. It has been suggested that the initial set due to the polymerization reaction of the resin-modified glass-ionomer cements may act to protect the cement from deterioration arising from early water contact (Um & Oilo, 1992). This may be especially helpful in the case of subgingival margins.

CONCLUSIONS

1. Vitremer Luting exhibited a seven-day water sorption, which was significantly greater than any of the other cements tested.

2. Fuji Duet exhibited a water solubility at seven days, which was significantly higher than any of the other cements in this study.

3. Vitremer Luting exhibited significantly less water solubility when compared to Fuji Duet or Advance, the other resin-modified glass-ionomer cements tested in this study.

4. Vitremer Luting exhibited a lactic acid solubility that was significantly higher than any of the other cements tested.

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Post Retention and Post/Core Shear Bond Strength of Four Post Systems

LW Stockton • PT Williams • CT Clarke

Clinical Relevance

The Para Post XT, because of its retentive capabilities and greater resistance to root fracture, is most likely to give successful clinical results in most situations.

SUMMARY

As clinicians we continue to search for a post system which will give us maximum retention while maximizing resistance to root fracture. The introduction of several new post systems, with claims of high retentive and resistance to root fracture values, require that independent studies be performed to evaluate these claims. This study tested the tensile and shear dislodgment forces of four post designs that were luted into roots 10 mm apical of the CEJ. The Para Post Plus (P1) is a parallel-sided, passive design; the Para Post XT (P2) is a combination active/passive design; the Flexi-Post (F1) and the Flexi-Flange (F2) are active post designs. All systems tested were stainless steel. This study compared the test results of the four post designs for tensile and shear dislodgment. All mounted samples were loaded in tension until failure occurred. The tensile load was applied parallel to the long axis of the root, while the shear load was applied at 450 to the long axis of the root. The Flexi-Post (F1) was significantly different from the other three in the tensile test, however, the Para Post XT (P2) was significantly different to the other three in the shear test and had a better probability for survival in the Kaplan-Meier survival function test. Based on the results of this study, our recommendation is for the Para Post XT (P2).

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INTRODUCTION

Even though the majority of the literature is unanimous in stating that posts do not reinforce teeth (Fan, Nicholls, & Kois, 1995; Lovdahl & Nicholls, 1977; Guzy & Nicholls, 1979; Trope, Maltz & Tronstad, 1985; Sorensen & Martinoff, 1984; Trabert, Caputo & Abou-Rass, 1978; Caputo & Standlee, 1987; Sorensen & Martinoff, 1984; Sorensen & Martinoff, 1985; Marshak, Helft & Filo, 1988; Sorensen, 1988; Ko & others, 1992; Robbins,1990; Morgano, 1996), a recent survey of US dentists found that 50% of those responding believed that a post does reinforce an endodontically-treated tooth (Morgano & others, 1994). There are several retrospective *in-vivo* studies (Sorensen & Martinoff, 1984; Roberts, 1970; Lewis & Smith, 1988; Torbjorner, Karlsson & Odman, 1995; Mentink & others, 1993) that report a higher failure rate of endodontically-treated restored teeth, particularly those that serve as abutments for a FPD or a RPD, when compared to vital teeth with artificial crowns (Sorensen & Martinoff, 1984; Hatzikyriakos, Reisis & Tsingos, 1992; Palmquist & Sodefeldt, 1994). The properties of restored or endodontically-treated teeth differ from those of natural or vital teeth, and these differences may be the cause for the higher failure rate reported for endodontically-treated teeth.

A study (Paphangkorakit & Osborn, 1997) that compared the maximum bite force of a natural upper central incisor to one with full coverage found that the average maximum bite force was significantly larger in the full-cover situation. This study suggested that mechanoreceptors that exist within the pulp play a more significant role in preventing overfunction than mechanoreceptors in the periodontium. Controversy exists regarding the quality of dentin in endodontically-treated teeth. Helfer, Melnick & Schilder (1972) found that pulpless dog teeth had 9% less moisture than vital teeth. Reeh, Messer & Douglas (1989) found that endodontic procedures reduced tooth stiffness by 5%. Carter, Sorensen & Johnson (1983) found that dentin from endodontically-treated teeth had significantly lower shear strength and toughness than dentin from vital teeth. Rivera, Yamauchi & Chandler (1988) suggested that the fracture resistance of endodontically-treated teeth is lower because the collagen intermolecular cross-links may be weaker. Sedgley & Messer (1992) suggest, on the other hand, that it is the cumulative loss of dentin and the pressoreceptive mechanism, and not the endodontic procedures that affect clinical performance.

Failure can occur as a result of root fracture, post bending or fracture, core failure or cement failure. Cement failure is preferred to tooth fracture since it usually allows for retreatment. In contrast, tooth fracture often necessitates extraction of the tooth.

Post fracture may allow retreatment, but often presents a considerable challenge in retrieval of the post without irreversibly mutilating the tooth. Purton, Chandler & Love (1998) suggests that less rigid, less retentive post designs are more likely to fail during normal function, and as a result, there is the potential for fracturing dentin, crushing cement, opening crown margins and allowing coronal leakage, all of which may compromise the endodontic treatment.

Because post-core restored teeth have a higher failure rate than vital teeth (Sorensen & Martinoff, 1984; Roberts, 1970; Lewis & Smith, 1988; Torbjorner & others, 1995; Mentink & others, 1993; Hatzikyriakos & others, 1992; Palmquist & Sodefeldt, 1994), restorative procedures that preserve pulp vitality are desirable. However, if endodontic therapy is unavoidable, minimizing the loss of sound tooth structure during endodontic and restorative procedures is therefore most important (Robbins, 1990; Gutmann, 1992; Sorensen & Engleman, 1990). It was determined (Hunter, Feiglin & Williams, 1989) that minimal root canal enlargement for a post does not substantially weaken a tooth. Another study (Sidoli, King & Setchell, 1997) found that teeth that were only endodontically treated had a higher resistance to fracture than post-core restored teeth.

The literature suggests that the major function of an endodontic post is to provide a retentive foundation on which to fabricate a restoration (Fan & others, 1995; Traber, Caputo & Abou-Rass, 1978; Assif, Bitenski, Pilo & Oren, 1993). However, considerable research has studied post retention and tooth post-core resistance to fracture (Fan & others, 1995; Gutmann, 1992; Sorensen & Engelman, 1990; Hunter & others, 1989). Factors identified that affect retention are post length, post diameter, post design, luting agents, method of luting, canal shape, preparation of the canal space and location in the dental arch (Stockton, 1999).

Controversy, however, exists concerning dowel design. Studies indicate that although threaded posts are more retentive than parallel-sided posts (Kurer, Combe & Grant, 1977; Ruemping, Lund & Schnell, 1979; Lepe, Bales & Johnson, 1996; Brown & Mitchem, 1987), the stresses generated during their placement can be significantly higher than stresses for passive posts (Ross, Nicholls & Harrington, 1991; Burns & others, 1990). The research suggests that clinicians should focus less on factors affecting retention and more on factors affecting resistance to root fracture (Sorensen & Martinoff, 1984). *In vitro* studies (Sorensen & Martinoff, 1984; Sorensen, 1988; Robbins, 1990; Morgano, 1996) confirm the importance of maintaining tooth structure bulk, and of minimizing stresses generated through post insertion to prevent tooth fracture (Burns & others, 1990).

Lambjerg-Hansen & Asmussen (1997) suggest that stability is far more important than retention, as the major forces that occur during function are more or less at right angles to the long axis of the post. Stability depends upon the stiffness and elastic limit of the post and the tensile/compressive strengths of the core material (Caputo & Standlee, 1987).

Studies have shown that combining a ferrule, with an artificial crown, of at least 1.0 mm of tooth structure apical to the tooth-core junction can significantly increase the fracture resistance of the tooth (Sorensen & Engleman, 1990; Sorensen, Engleman & Mito, 1988).

The ferrule can also improve resistance to dynamic occlusal loading, help maintain the integrity of the cement seal of the artificial crown retainer and reduce the potential for stress concentration at the junction of the core and the post (Libmann & Nicholls, 1995).

The introduction of several new post systems which claim superior retention and resistance to tooth frac-

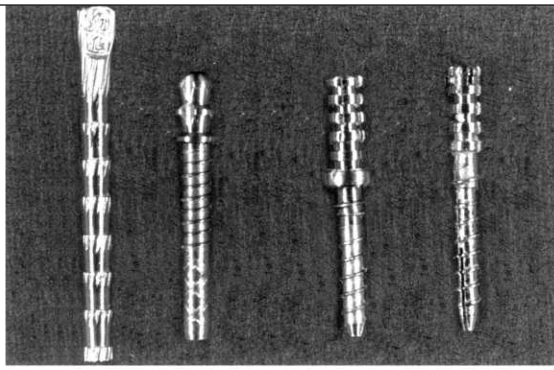

Figure 1. *1-Para Post Plus; 2-Para Post XT; 3-Flexi-Flange; 4-Flexi-Post.*

ture require that independent studies be performed to evaluate these claims.

This study evaluated the post retention and the fracture resistance of endodontically-treated teeth restored with four different post systems. (Figure 1).

METHODS AND MATERIALS

Eighty human maxillary incisor and canine teeth were selected and randomly assigned to eight groups of 10 teeth. In order to reduce the variation caused by different morphologies and remaining dentin, teeth that were free of visible microfractures and that had at least 1.5 mm of dentin proximal to the post space at the coronal surface following post preparation were selected. Measurements of the maximum buccolingual and mesio-distal dimensions at the CEJ were made for each tooth.

Groups 1, 2, 3 and 4 evaluated retention. Group 1 received a Para Post Plus (P1) {Whaledent/Coltene, New York, NY, 10001}; Group 2 received a Para Post XT (P2) {Whaledent/Coltene, New York, NY, 10001}; Group 3 received a Flexi-Post post (F1) {Essential Dental Systems Inc, S Hackensack, NJ 07606}; and Group 4 received a Flexi-Flange post (F2) {Essential Dental Systems Inc, S Hackensack, NJ 07606}.

Groups 5, 6, 7 and 8 evaluated the shear strength of the restored samples. Groups 5, 6, 7 and 8 received a P1, P2, F1 and F2 post, respectively and a Ti-Core composite core (Essential Dental Systems Inc, S Hackensack, NJ 07060).

The crowns of all 80 teeth were removed, using a carborundum disc, 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 (Moyco/Union Broach, York, PA, 17402) #2, 3 and 4 were used to flare the coronal half of the canal space and vertical condensation of the gutta percha was used with Kerr's Pulp Canal Sealer (Kerr Manufacturing Co, Romulus, MI 48174) placed on the apical 5 mm of the gutta percha point. The roots of Groups 1, 2, 3 and 4 were mounted vertically in methyl methacrylate resin (Instant Tray Mix, Lang Dental Manufacturing Co Ltd, Wheeling, IL 60090). The roots of Groups 1, 2, 3 and 4 were prepared using the Whaledent (Whaledent/Coltene, New York, NY, 10001) Para Post Plus, Para Post XT, Flexi-Post (Essential Dental Systems Inc, S Hackensack, NJ, 07606) and the Flexi Flange (Essential Dental Systems Inc, S Hackensack, NJ, 07606) drills, respectively, to a maximum depth of 10 mm below the coronal surface of the root. The desired post size, #6P1 and P2, and #1 F1 and F2, respectively, were tried to ensure a proper fit. The post space was washed and dried thoroughly. All posts were luted with Flexi-Flow (Essential Dental Systems Inc, S Hackenhack, NJ 07606) composite cement. The cement was mixed according to the manufacturer's instructions and placed in the post space with a hand-held lentulo spiral and onto the post. All posts of each group were inserted following the manufacturer's instructions. Completed samples were stored in 37°C water for 48 hours. The mounted samples (Figure 1) were then loaded in tension (Rheile FS-5 Screw Power Testing Machine, American Machine and Metals, East Moline, IL) until failure occurred. The load at failure was recorded and the data analyzed using ANOVA followed by the least square means test.

The roots of four groups of 10 teeth were prepared using the same technique as for Groups 1, 2, 3 and 4. The 40 samples were mounted in methyl methacrylate 3 mm apical of the coronal surface of the root. Post size number 6 P1 and P2, and #1 F1 and F2 posts were luted to place following the same luting and insertion techniques as for Groups 1 to 4.

All posts had a maximum length of 14.5 mm. The coronal portion of the root surface of all samples was etched for 30 seconds with 32% phosphoric acid, washed and lightly dried and painted with seven coats of a mixture of Primers A and B (Bisco Dental Products, Itasco, IL 60143). This primed surface was thoroughly air dried for five seconds. A coat of Pre-Bond Resin (Bisco Dental Products, Itasco, IL 60143) was placed on the coronal surface and air thinned. An IB-Swiss (IB Williams AG, Mauren, Switzerland, CH-8576) crown form, filled with Ti-Core composite core material mixed according to the manufacturer's instructions, was seated to place until complete set had occurred. 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 was removed using a fine grit high speed diamond and coarse Pop-On discs (3M Dental products, St Paul, MN 55133-3275) to ensure a butt-joint at the root/composite interface (Figure 2).

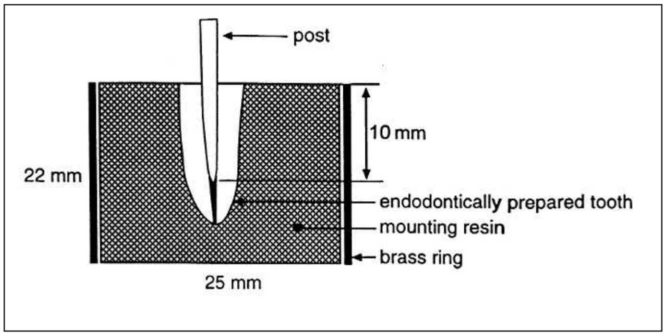

Figure 2. *Configuration of Groups 1, 2 and 3 and four samples mounted in resin in a brass ring.*

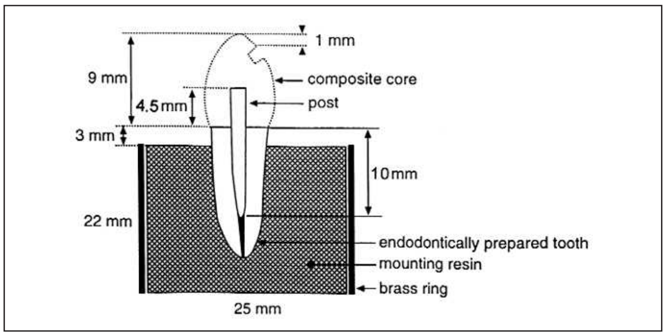

Figure 3. *Configuration of Groups 5, 6 and 7 and eight samples mounted in resin in a brass ring.*

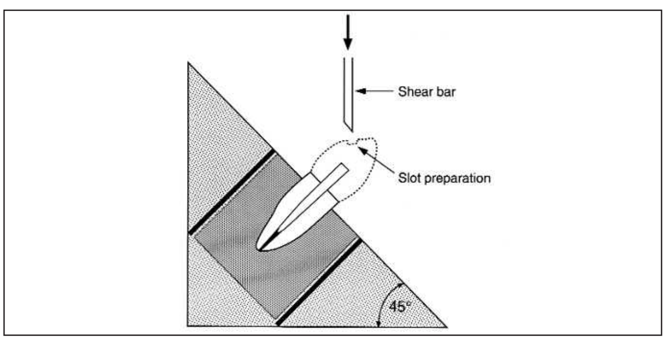

Figure 4. *Sample holder with mounted sample showing slot penetration. Note the base of the slot is 1 mm from the incisal edge and is perpendicular to the direction of the load application. The arrow shows the direction of the load application.*

Table 1: *Post Retention Strength*

Post Type	Mean Load (kg)	S.D	Range (kg)
F1	58.9	(21.27)	29.5 - 83.6
P1	38.8	(19.77)	13.6 - 76.4
P2	38.7	(20.04)	16.1 - 67.9
F2	21.3	(13.18)	5.7 - 40.5

Mean load required to debond the four post groups from the endodontically-treated teeth. The vertical line connects values that are not statistically different (p<0.05).

The completed samples were stored in water at 37°C for 48 hours, then tested. Shear strength was determined by applying an increasing load 1 mm apical of the incisal edge and at 45°C to the long axis of the root until failure occurred (Rheile FS-5 Screw Power Testing Machine, American Machine and Metals, East Moline, IL). The load at failure as well as the site of failure was recorded, and the data analyzed using ANOVA followed by the least square means test. Figure 3 shows the custom-made sample holder that enabled the load to be applied on the samples at 45°C to the long axis of the root. A small slot (Figure 4), placed on the core surface prior to testing, received the shear blade, assuring that the load was applied at the 1 mm distance from the incisal edge.

RESULTS

The retention strengths of the luted P and F posts are shown in Table 1. There was no statistical difference between the P1 and P2 posts; however, the F1 post was statistically different from the P1 and P2 posts ($p<0.022$), and from the F2 post ($p<0.0001$). The P1 and P2 samples had values greater than the F2 samples ($p<0.046$).

The load at failure of the posts 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 statistical analysis revealed that only the P2 posts were different from the P1 and F1 posts ($p<0.006$, 0.004, respectively).

Eight of the F1 samples, seven of the P1 samples and six of the F2 samples failed as a result of root fracture. Only one of the P2 samples had a root fracture, while eight failed as a result of the post debonding from the root. There was a total of three core fractures, one of which was as the result of an air bubble within the core material.

Figure 5 shows the results of the Kaplan-Meier Curve survival function test. One-hundred percent survival was achieved for the F1 group up to 18.2 kg; the F2 group up to 22.7 kg; the P1 group up to 25 kg; and the P2 group up to 28.6 kg. The survival rate at the maximum incisal bite force of 37.7 kg (Paphangkorakit & Osborn, 1997) was 40% of the F1 group; 80% of the F2 group; 51% of the P1 group and 72% of the P2 group. The survival rate of the F2 group decreased from 80% to 52% as the load increased from 36.4 kg to 43.2 kg. The P2 group survival rate remained at 72% until the load reached 44.5 kg, when it decreased to 60% and remained at 60% until the load reached 62.7 kg.

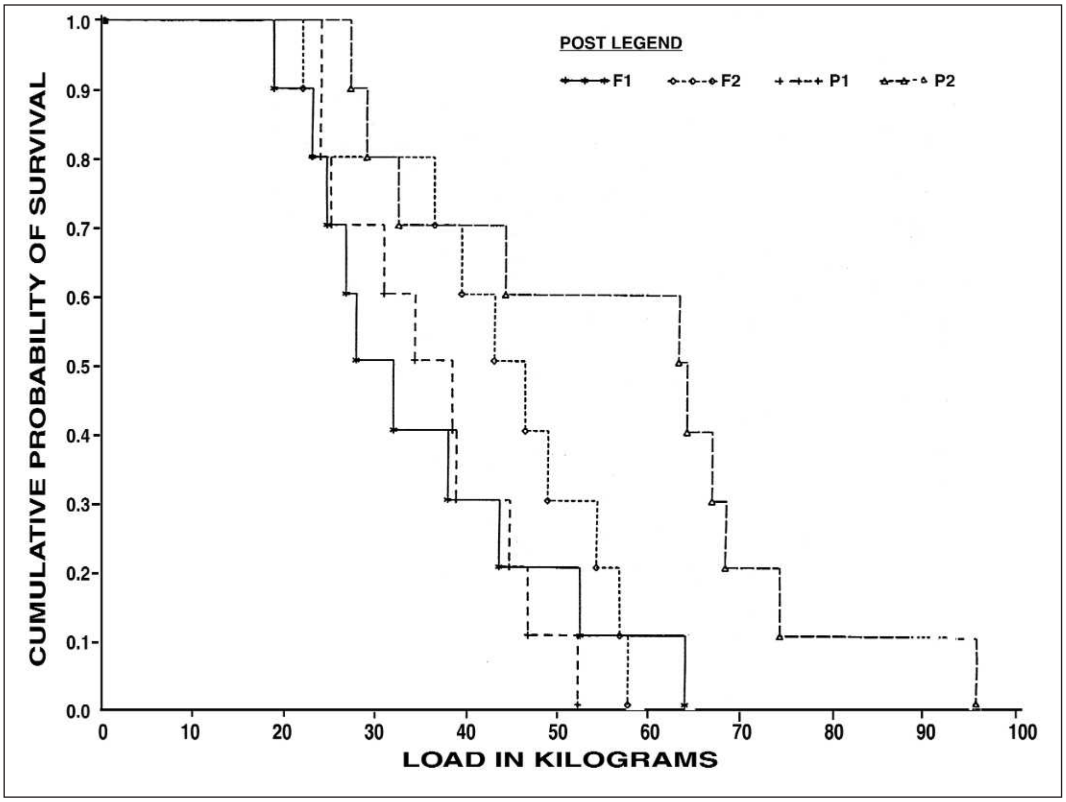

Figure 5. *Kaplan-Meier Curve showing survival probability.*

DISCUSSION

The literature (Fan & others, 1995; Lovdahl & Nicholls, 1977; Guzy & Nicholls, 1979; Trope & others, 1985; Sorensen & Martinoff, 1984; Trabert & others, 1978; Caputo & Standlee, 1987; Sorensen & Martinoff, 1985; Marshak & others, 1988; Sorensen, 1988; Ko & others, 1992; Robbins, 1990; Morgano, 1996) supports the concept that instead of reinforcing a tooth, the insertion of a large post can actually weaken the tooth (Sorensen & Martinoff, 1984).

The tooth-related factors that have been recognized as determinants for successfully restoring endodontically-treated teeth are the postion of the tooth in the arch, (Sorensen & Martinoff, 1984), the tooth/root length, the remaining bulk of tooth structure (Sorensen & Martinoff, 1984) and post-core stiffness (Ross & others, 1991). Of these, the key factor is the maintainance of coronal tooth structure (Sorensen & Martinoff, 1984; Sorensen & Engelman, 1990). The stiffness of the entire post-core assembly must be able to resist, with the least possible deformation, the forces of mastication. If not, the likely result is restoration and/or tooth failure. The dentist must therefore select an endodontic post with high stiffness, high-yield strength and a high degree of retention (Ross & others, 1991). In addition, the dentist must maintain the bulk of the remaining tooth stucture (Sorensen & Engelman, 1990).

Table 2: *Post/Core Shear Strength*

Post Type	Mean Load (kg)	S.D	Range (kg)	No. of Root Fractures
P2	58.2	(22.41)	27.0 - 95.6	1
F2	42.6	(12.78)	21.8 - 57.5	6
F1	34.9	(14.35)	18.6 - 63.9	8
P1	33.3	(14.35)	23.9 - 52.0	7

Mean shear failure loads for the post and core restored groups. The vertical lines connect values that are not statistically different ($p<0.05$*).*

Contrary to expectations, the group with the highest mean retention strength had the second lowest mean shear strength, and the two post groups with the lowest mean retention strength had the highest mean shear strength. Some factors that affect retention (Sorensen, 1988; Stockton, 1999) and pertain to the posts used in this study are the surface area of the post; the number and the profile of the threads and the presence/absence of a split in the post shank.

The F1 post had the highest mean retention strength, likely as a result of having a higher number of threads as compared to the F2 and P2 posts and having higher profile threads, particularly the most occlusal threads, than the P2 post. The F2 post, because of the flange, has a decreased active length and, therefore, fewer threads and a decreased surface area.

Although one would expect the P2 group to have higher retention strengths than the P1 group, under close examination, the P2 threads are low profile, interrupted and wedge-shaped, which would allow the post to be pulled out more easily than the P1 post, which has a circumferential horizontal ledge every 2 mm.

The authors hypothesize that resistance to lateral displacement of a post can be increased by:

a) moving the loading point away from the occlusal surface of the root. This can be accomplished with a stiffer post; with the threaded section of the post placed apical to the occlusal surface of the root; and having a gap between the post and the canal walls at the occlusal surface of the root.

b) spreading the load over a wider area. This can be accomplished using a larger diameter post and using a post with an internal or external flange. However, a large diameter post and one with an internal flange can reduce the fracture resistance of the root by reducing the bulk of the tooth at the coronal surface.

c) reducing the dentin preload. This can be accomplished with a non-threaded, passively-inserted post.

The low mean shear values for the F1 post can, therefore, be explained, as it has threads that engage dentin the entire length of the root, with the highest profile threads toward the coronal surface of the post where high stress values have been reported (Burns & others, 1990).

The threads on the F2 post end just apical to the flange, which sits passively in the circular preparation. There would be minimal stresses at the coronal surface of the root around the flange until the load is applied, and because of the flange, this load would be spread over a larger area. The F2 samples were, therefore, able to withstand fairly high load values. However, perhaps because of the loss of coronal tooth structure during the preparation for the flange, they sustained a high number of root fractures.

Although the manufacturer reports the diameter of the F1 and F2 posts to be 1.4 mm, a measurement of the two posts reveals that this measurement only exists at the point of the highest profile thread. Since the apical 5 mm of the shank has a split, the stiffness of the post is reduced in this region and more of the load is applied to the root at the occlusal surface.

The higher shear strengths of the P2 group, as compared to the P1 group may, in part, be related to the small external flange on the P2 post that may allow the force to be distributed over a larger area than the P1 post, resulting in considerably fewer root fractures. The higher number of root fractures for the P1 group may be explained in that the P1 post generated maximum loading right at the occlusal surface.

The parallel-sided design of the P1 and P2 posts necessitates removal of apical dentin to permit fully seating this post. In those clinical situations where a sufficient bulk of apical dentin may not exist to permit complete root prepartion without weakening the root or causing a perforation, the manufacturer suggests trimming the apical portion of the post. Whether or not this procedure would affect the mechanical performance of this post will require investigation.

This study shows that posts (F2, P2) with lower retentive values can have higher shear strengths because of post design and not as a result of the active part of the post. Although both the F2 and P2 groups had mean shear strengths in excess of the maximum bite force of 37.7kg for a maxillary central incisor, as reported by Paphangkorakit & Osborn (1997), the F2 group had significantly more root fractures than the P2 group.

A ferrule effect of at least 1 mm of tooth structure between the crown preparation and the tooth/core junction has been shown to double the fracture resistance (Sorensen & others, 1988). Sorensen & others (1988) suggest it is critical that the tooth be prepared with minimal taper to ensure the success of the restoration. One may speculate that by following the guidelines set forth by Sorensen & others (1998) for the ferrule, teeth may be successfully restored using any of the posts examined in this study.

The authors suggest that the following factors may increase the resistance of the tooth to fracture:

a) Use a stiff post.

b) Maximize retention without unnecessarily removing valuable dentin and without inducing potentially harmful internal stresses at the occlusal surface of the root. Use a post design that will assure that the post applies little load to the tooth near the root's occlusal surface.

c) Incorporate a ferrule of at least 1 mm on those endodontically-treated post-restored teeth requiring coronal coverage.

CONCLUSIONS

There is no universal post and core system that is optimal for all teeth. Individual anatomic and clinical conditions must be considered in order to select the type of post needed for each case. Although the Para Post XT (P2) did not attain the high tensile values of the Flexi-Post (F1), it had significantly higher values in the shear test and, perhaps most importantly, had a better probability in the Kaplan-Meier survival function test. The Para Post XT is, therefore, most likely to give successful clinical results in most situations.

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Effect of Three Surface Sealants on Marginal Sealing of Class V Composite Resin Restorations

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Clinical Relevance

The rebonding agent, when applied on polymerized composite resin restorations, contributes to a reduction in the degree of microleakage at dentin and cementum margins, thus increasing the marginal integrity.

SUMMARY

This study evaluated *in vitro* **the effectiveness of three different surface sealants (Fortify, Protect-it! and Optiguard) on the marginal sealing of Class V light-activated composite resin restorations (Prodigy). For this purpose, 20 sound noncarious human premolars extracted within a six-month period were selected. Class V cavities with the occlusal margin in enamel and cervical margin in cementum were prepared in both buccal and lingual surfaces. The teeth, randomly assigned in four groups with 10 cavities in each group, were restored with composite resin after applying an adhesive system (Optibond FL). After the finishing and polishing procedures, the restorations were covered with a specific surface sealant, except for the control samples, which were not sealed. After placing restorations, the specimens were thermocycled and immersed in a 50% silver nitrate solution (tracer agent) for eight hours, sectioned longitudinally and analyzed for leakage using an optical microscope in a blind study with three examiners. The marginal microleakage was evaluated at the occlusal and cervical interfaces and compared among the four groups using the Kruskall-Wallis and the Wilcoxon Tests. There was better sealing at the occlusal margin, and in this region, there were no statistically significant differences among the materials (*p*>0,05). In the cervical region, Fortify and Protect-it! showed improved results over the Control Group, and Optiguard showed similar results to the Control Group (without sealing).**

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INTRODUCTION

The introduction of the acid-etching technique by Buonocore, (1955) undoubtedly represented a great evolution for Operative Dentistry. It made possible the development of adhesive restorative systems. Until then, the bonding ability of materials to dental structures was quite limited. Studies have been carried out since, with a view to improving the characteristics and properties of these materials (Hansen & Asmussen, 1985). Many of the problems presented by the earlier generations of restorative materials, such as accentuated polymerization shrinkage, a high degree of wear and lack of retention, have been significantly minimized.

Nevertheless, marginal microleakage control, in spite of the improvements obtained, is still a challenge for clinicians and researchers. Its consequences, such as color alteration, staining due to marginal breakdown, recurrent decay, pulpal inflammation and postoperative sensitivity (Pashley, 1990; Triadan, 1987) considerably limit the longevity of the restorations and could affect the vitality of the dental pulp.

In an attempt to overcome this problem, using a layer of low-viscosity resin over composite restoration has been investigated. This resin should penetrate into the interfacial microgaps, especially in the dentin and cementum margins, thus promoting better marginal sealing. In addition, this material would fill the structural microdefects formed during the insertion technique and the finishing and polishing procedures, thus increasing the wear resistance of the restoration.

Initially, there were attempts to use fissure sealants or bonding agents, (Reid, Saunders & Chen, 1991; Torsteson, Brännstrom & Mattsson, 1985; Mcourt & Eick, 1988; Tjan & Tan, 1991) as covering agents. However, the success of the technique depended on covering agents' ability to penetrate into the microdefects because of capillary action, which is directly related to its viscosity and wettability. So, the use of any low-viscosity resin system may not achieve the required effectiveness due to discrepancies in the formulation, dilutant agents, viscosity modifiers and curing mechanisms (Tjan & Tan, 1991).

Some years ago, materials specifically developed for rebonding of polymerized restorations, referred to as covering agents or surface sealants, were introduced. Today, several commercial products are available, such as Fortify (Bisco Inc, Itasca, Il 60143), Optiguard (Kerr Corporation, Orange, CA 92667) and Protect-it! (Jeneric-Pentron Inc, Wallingford, CT 06492). They are resin materials with low-viscosity and high-flow rate, present similar compositions and their application technique is relatively simple.

This study evaluated the effect of three surface sealants on marginal sealing of Class V composite resin restorations, analyzing the performance of the agents in preventing or reducing microleakage.

METHOD AND MATERIALS

Twenty sound, noncarious human pre-molars extracted within a six month period were selected and stored in saline solution at room temperature. The teeth were cleaned with a scaler and pumice in a dental prophylactic cup. Class V cavities were prepared in each tooth, one in each surface, buccal and lingual, with the occlusal margin in enamel and cervical margin in cementum, using a #329 bur at high speed with air/water spray. The perimeter of the cavity was delineated on the tooth surface with a marker pen, and the mesiodistal width and occlusalgingival measurement were 4 mm x 3 mm, respectively. The depth of the cavity was determined by the entry of the bur (2 mm).

Prior to placing the restorations, the cavities were finished manually with sharp instruments. The cavosurface angle in enamel was beveled with a diamond point #3118, and the cementum margin was kept finishing at 90° with the external surface. The specimens were kept humid until the restorative procedures were carried out.

The restorations were placed following manufacturers' instructions. First, the cavities were etched with a 37% phosphoric acid gel (Gel Etchant, Kerr Corporation, Orange, CA 92667) for 20 seconds, rinsed for 20 seconds and gently dried with absorbent paper to keep the tooth surface moist, according to the wet-bonding technique (Kanka J, 1991). Optibond FL primer (Kerr Corporation, Orange, CA 92667) was applied over enamel and dentin surfaces with a light scrubbing motion for 30 seconds and air dried gently for five seconds. After the glossy appearance of the surface was observed, Optibond FL adhesive (Kerr Corporation, Orange, CA 92667) was applied (one coat), air-thinned and light cured for 30 seconds with a visible light-curing unit with an output of 400 mW/cm^2 (Optilux 400, Demetron, Danbury, CT 06810). A microhybrid light-activated composite resin (Prodigy, Kerr Corporation, Orange, CA 92667) was inserted with appropriate instruments according to an incremental fill technique; each increment, of about 1 mm thick, was light cured for 40 seconds. The finishing procedures were accomplished by removing the roughest excesses, then the specimens were stored for seven days in distilled water at 37°C and 100% relative humidity. After one-week, final polishing of the restorations was carried out with Sof-Lex disks (3M Dental Products, St Paul, MN 55144).

The samples were randomly divided into four groups of 10 restorations each: one control group that did not receive surface sealing and three other groups where the buccal and lingual restorations were sealed with one of the three agents (Fortify, Optiguard or Protect-it!),

Table 1: *Materials Tested*

Material	Batch No.	Manufacturer
Prodigy	710328	Kerr Corporation, Orange, CA, USA
Fortify	109246	Bisco Inc, Itasca, IL, USA
Protect-it!	801980	Jeneric-Pentron, Inc, Wallingford, CT, USA
Optiguard	710298	Kerr Corporation, Orange, CA, USA
Optibond FL	Primer: 25881 Adhesive: 25882	Kerr Corporation, Orange, CA, USA

Table 2: *Groups Studied*

Groups	n (specimens)	Adhesive System	Composite Resin	Surface Sealant
1	10			Control (without sealing)
2	10	Optibond FL	Prodigy	Optiguard
3	10			Fortify
4	10			Protect-it!

Table 3: *Distribution of Microleakage Scores*

		Category of Microleakage				
Group	**Enamel Margins**	**0**	**1**	**2**	**3**	**n**
1	Control	10	0	0	0	10
2	Optiguard	10	0	0	0	10
3	Fortify	9	0	1	0	10
4	Protect-it!	9	1	0	0	10
Group	**Cervical Margins**	**0**	**1**	**2**	**3**	**n**
1	Control	0	4	3	3	10
2	Optiguard	1	4	5	0	10
3	Fortify	5	3	0	2	10
4	Protect-it!	4	4	1	1	10

according to the group. The materials and the groups studied are described in the Tables 1 and 2, respectively.

For the groups that received a rebonding agent, the surface and adjacent margins of the restorations (2 mm beyond the tooth/restoration interface) were etched with 37% phosphoric acid gel for 15 seconds, rinsed for 15 seconds, gently dried with compressed air, then the covering agent was applied and light cured for 20 seconds according to manufacturers' specifications.

The specimens were subjected to a thermocycling regimen of 600 cycles between 4°C and 55°C waterbaths. Dwell time was one minute, with a three-second transfer time between baths.

In preparation for the dye penetration test, the specimens were dried superficially and two coats of nail varnish were applied to the entire specimen surface, leaving a 2 mm window around the cavity margins. The samples were then immersed in a 50% silver nitrate solution (Miranda, 1994) for eight hours. Then, the surface-adhered silver nitrate was removed by rinsing in tap water. The teeth were included in blocks of a chemically-activated acrylic resin (JET, Clássico, São Paulo, SP 05458-001) and sectioned longitudinally in a buccolingual direction with a diamond saw in the sectioning machine Minitom (Struers A/S, Copenhagen, Denmark) providing two-to-four cuts 1-mm thick. The sectioned surfaces were exposed to the light of a photoflood lamp for one hour. This procedure was necessary to reveal the silver nitrate that, once exposed to the light, acquires a dark color, allowing the areas where there was dye penetration to be identified.

The degree of marginal microleakage was determined by the penetration of the tracer agent, starting from the margins of the restoration towards the axial wall. The margins were analyzed separately by viewing them under an optical microscope (Nikon Inc Instrument Group, Melville, NY 11747) with a x4 magnification in a blind study with three examiners. The following criteria was used to score penetration by the silver nitrate: 0=Absence of dye penetration; 1=Dye penetration up to the half of the extension of the walls; 2=Dye penetration to more than half of the extension of the walls without reaching the axial angle; 3=Dye penetration in the whole extension of the walls and in the direction to the pulp.

The Kruskal-Wallis Test was used to statistically analyze the results of the four groups in the occlusal and the cervical region. The Wilcoxon Test analyzed the difference between the occlusal and cervical regions.

RESULTS

The results were logged in tables and the modus of the obtained scores was determined. The scores observed in the different groups and regions are represented in Table 3 and Figures 1 and 2. In the occlusal region, all the groups presented similar results; there were no statistically significant differences among them (p>0,05). In the cervical region, there were statistically significant differences (p ± 0,05) between Groups 3 and 4 (Fortify and Protect-it!) in relation to the Control Group; the sealed groups, giving better marginal sealing than the Control Group. Group 2 (Optiguard) showed statistical similarity with the Control Group (Group 1).

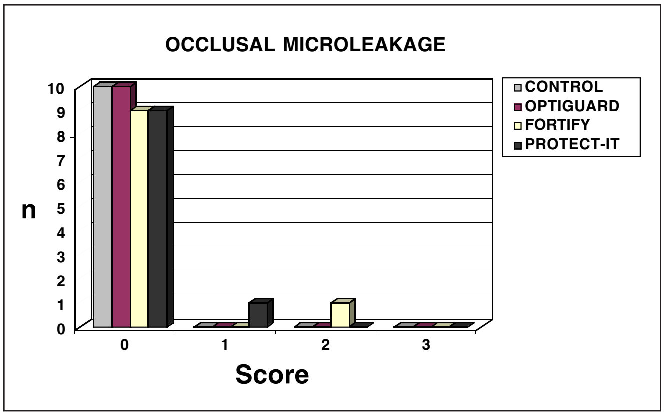

Figure 1. *Graph of marginal microleakage scores: occlusal margin results (n= number of specimens).*

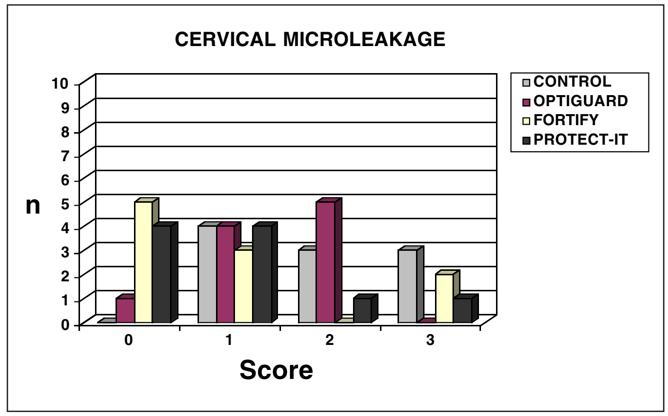

Figure 2. *Graph of marginal microleakage scores: cervical margin results (n= number of specimens).*

When comparing the cervical and occlusal regions, a statistically significant difference ($p \pm 0,01$) was observed; the occlusal margin presented better marginal sealing than the cervical region.

DISCUSSION

Many attempts to prevent the occurrence of microleakage in tooth/restoration interface have been made, thus maintaining the integrity of the restorations in order to increase their longevity. Incremental fill techniques have been used with the objective of minimizing the effects of the polymerization shrinkage. These techniques have shown *in vitro* to reduce the marginal polymerization contraction gap by 25% (Torstenson & Oden, 1989). Significantly less leakage at restoration margins have been reported by utilizing a glass-ionomer base in sandwich technique (Sidhu & Henderson, 1992). Dentin bonding agents have been substantially improved and have been effective in reducing microleakage in the gingival margin but not eliminating it entirely (Miranda, 1994). Formerly, several systems have been developed to promote adhesion of the restorative material to the dentin substratum, considerably improving the performance of those materials, decreasing the microleakage in the gingival margin, but in a general way, all efforts to completely eliminate the marginal contraction gap and totally prevent the occurrence of microleakage have failed (Johnson, Powell & Gordon, 1991; Munro, Hilton & Hermesch, 1996).

Microleakage occurs because of the microgap formation along the interface. This can be attributed to several factors: the polymerization shrinkage that causes tensions in the tooth/restoration interface, marginal microcracks formation and consequently, flaw in the adhesion of the material with the dental structure. Once this union is broken, it is not established again (Mondelli, 1998) different coefficient of thermal expansion between composite and tooth structure; the insertion phase that is critical and should be carried out in increments (incremental fill technique) to decrease the effects of the contraction of the material during photopolymerization, and also the finishing and polishing procedures, because using rotating instruments can generate tensions in the interface creating microfractures or microgaps. Some authors, such as Batitucci (1991) and Barreiros (1994), recommend final polishing after 21 days in order to wait for composite resin hygroscopic expansion to be completed, and hence, compensate partly for the contraction suffered by the material during the polymerization, therefore, reducing the magnitude of the gaps created.

In order to fill the microdefects and microcracks formed between the restorative material and the tooth structures, authors, such as Judes & others (1982), began to indicate the application of a low-viscosity resin to the margins of polymerized composite resin restorations so that these agents could deeply penetrate into the structural microgaps and the microfractures could promote marginal sealing.

Reid & others (1991) and Tjan & Tan (1991) studied several resin materials with low viscosity as covering agents. According to those researchers, using fissure sealants (chemically and light activated) and bonding adhesives was ineffective in preventing the marginal infiltration in Class V composite resin restorations. This is possibly due to the fact that they are resin materials as well and, therefore, undergo polymerization contraction on curing. Besides, the degree of penetration of the surface sealant, and consequently its effectiveness in sealing the interface, depends on its viscosity (this should be low for a predetermined time so that the agent can penetrate more deeply in the gaps before the start of the polymerization) and the capacity to wet the dental structures and the restoration, and the addition of opaquing components contributes to the decrease in the flow and wettability of the material.

The ideal material to fill the structural microdefects and microfractures should have enough flowing to allow a good wetting and appropriate filling of the gaps. It must be compatible with the restoring material and the union agent and have a coefficient of expansion and contraction similar to tooth structure (Reid & others and Tjan & Tan (1991).

Torstenson & others (1985) reported that surface sealants should be applied after the polymerization of the composite resin but before finishing and polishing. It is recommended because finishing may block the microgaps with debris and prevent the penetration of the covering agent applied on polymerized restoration. On the other hand, when the composite is finished, any excessive heat generated during the finishing procedures could result in the reopening of the marginal gaps due to the difference in the coefficient of thermal expansion between composite and tooth structures (Yu & others, 1990). In that way, other authors recommended to place the rebonding agent after finishing the restoration (García-Godoy & Malone, 1987; Tjan & Tan, 1991).

Clinical studies (Dickinson & others, 1990; Dickinson & Leinfelder, 1993) have demonstrated that eliminating the surface and subsurface microstructural defects by placing a surface penetrating sealant, Fortify, results in a significant reduction in the generalized wear of composites (*The Dental Advisor*, 1994). Other studies (Kawai & Leinfelder, 1992) confirmed that the surface penetrating sealant effectively reduced the generalized wear but only if the filler particle size is greater than 1 mm; the wear of composites containing submicron-sized filler particles was not affected by the sealant. However, it was found that, regardless to the particle size of the composite, the sealant enhanced marginal integrity.

Although much detail is not given by the manufacturers, it is known that the surface penetrating sealant consists of a BIS-GMA resin and the polymer was modified by adding lower molecular weight monomers, consisting of TEGDMA & THFMA, with the specific function of controlling viscosity and wetting characteristics (Bisco Dental Products), showing potential for penetrating and filling microstructural defects as small as 1 or 2 mm (Kawai & Leinfelder, 1993). The polymerization of the agent in the defects will lead the weakened surface to become more resistant to wear (Shinkai, Suzuki & Leinfelder, 1994).

In other research (Miranda, 1994), improved resistance to interfacial staining was observed on marginal integrity (with a consequent decrease in the marginal microleakage) and on superficial texture/smoothness.

Munro & others (1996) evaluated the effect that some rebonding agents have on the microleakage of Class V composite restorations with and without etching restoration margins. The authors reported that etching the gingival margin with 37% H_3PO_4 solution prior to rebonding did not improve the ability of the agent to prevent microleakage compared with not-etched groups. According to this experiment, etching the gingival margins could be contraindicated in order to reduce the risk of ditching the cementum and to obtain less opening of dentin tubules.

Barone, Smithand & Dicken (1999) also observed that re-etching the margins did not improve microleakage scores over those in the nonetched groups. These authors still concluded that microleakage around Class V restorations was improved by applying a lightly filled light-cured sealing resin.

With similar characteristics and the same objective that Fortify, other materials, such as Protect-it! and Optiguard were launched. This study observed that Fortify and Protect-it! effectively improved the marginal seal. Nevertheless, this did not occur with Optiguard, when compared with the control group. Further investigation is warranted to confront or to confirm the results of the performance of those materials presented in this article.

CONCLUSIONS

The results obtained in this *in vitro* evaluation showed that applying a low-viscosity surface penetrating sealant on a polymerized composed resin restoration produces a viable improvement in the reduction of marginal microleakage. The covering or rebonding agents offer the clinician a technique that significantly enhances interfacial integrity, increasing the life of the restorations. The surface sealing technique is quite simple and requires little additional clinical time. Using a material with specific characteristics of wettability and viscosity that can penetrate the microcracks formed on the surface and along the interface of the restoration is strongly recommended. Otherwise, its application will be ineffective.

The longevity of a rebonding agent in the microgaps is unknown (Munro & others, 1996), but according to Dickinson & Leinfelder (1993), its effectiveness could be enhanced if the material was reapplied biannually; such a recommendation can be based upon the probability that adjacent material could be lost to wear over a two-year period.

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Symposium Agenda

Friday, September 15, 2000

7:00-10:00 Registration

7:45-8:00 Introduction and Welcome
W Dan Sneed

Theme 1: Non-Restorative Approaches

8:00-8:50 Current concepts of dental caries and its prevention: The role of third party insurers
Maxwell H Anderson

8:55-9:45 Risk assessment
Kenneth J Anusavice

9:45-10:00 Break

10:00-10:50 Remineralization
Lawrence C Chow

10:55-11:45 Gene replacement therapy
Jeffrey D Hillman

11:50-12:40 Potential for vaccines in the prevention of carious lesions
Michael W Russell

12:40-1:00 Panel Discussion – (Research, Treatment Decisions, Caries Risk, Probiotics)

1:00-2:00 Lunch

2:00-2:50 Ways to remove roadblocks to advancement and implementation of knowledge in the field of biomimetics
Norman S Braveman

2:55-3:45 Assessment of current approaches to dental education
Mark A Latta

3:50-4:40 Ways underserved populations could benefit from new approaches
Charles R Hook

4:45-5:00 Panel Discussion – (Barriers to Changing Practice and Education Related to Non-restorative Techniques)

Saturday, September 16, 2000

Theme 2: Metallic Restorative Materials and Historical Standards

8:00-8:50 Performance standards for competitive dental materials
E Steven Duke

8:55-9:45 Mercury, its impact on the environment and its biocompatibility
John Osborne

9:45-10:00 Break

10:00-10:50 Gold as a historic standard & role for the future
Cleveland T Smith

10:55-11:45 Research into non-Hg containing metallic alternatives
Frederick Eichmiller

11:45-12 noon Panel Discussion – (Amalgam vs. Non-Hg Containing Alternatives)

12 noon -1:00 Lunch

Theme 3: Conservation Dentistry Through Adhesion and Non-Metallic Materials

1:00-1:50 Adhesives & cements to promote preservation dentistry
Bart Van Meerbeek

1:55-2:45 Recent commercial composite formulations
M Mike Suzuki

2:45-3:00 Break

3:00-3:50 Indirect resin & ceramic systems
Anne Peutzfeldt

3:55-4:45 Various forms of inonomers
Reinhard A Hickel

4:45-5:00 Panel Discussion – *Ed Swift* (Are Non-metallic Restoratives Viable as Amalgam Replacements?)

Sunday, September 17, 2000

Theme 4: Future Materials and Biocompatibility:

8:00-8:50 Direct posterior composite restorations
Didier Dietschi

8:55-9:45 Future polymers
Jack L Ferracane

9:45-10:00 Break

10:00-10:50 Future ceramic systems
Jean-Francois Roulet

10:55-11:45 Biocompatibility of restorative materials
Arne Hensten Pettersen

11:45-12 noon Panel discussion – *Dorothy McComb* (Future Materials Development to Promote Conservation and Prevention)

12:00-12:30 Directions for future research/Summary
Ivar A Mjör

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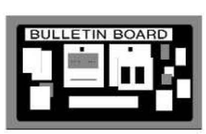

Correction

In our last issue (Vol 25-4 July/August 2000), we printed the incorrect address for Dr Sara Gordon, author of the article *Foreign Body Gingivitis Associated with a New Crown: EDX Analysis and Review of the Literature* (p 344-348). Dr Gordon's correct address is:

Dr Sara Gordon
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University of Detroit Mercy
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We apologize to both Dr Gordon and our readers for the error and any inconvenience it may have caused.

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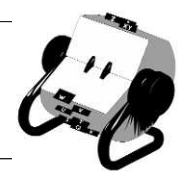

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