OPERATIVE DENTISTRY

july/august 2002 • volume 27 • number 4 • 317-420

(ISSN 0361-7734)

OPERATIVE DENTISTRY

JULY/AUGUST 2002 • VOLUME 27 • NUMBER 4 • 317-420

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.

Subscriptions: Fax (317) 852-3162

Operative Dentistry (ISSN 0361-7734) is published bimonthly by *Operative Dentistry,* Indiana University School of Dentistry, Room S411, 1121 West Michigan Street, Indianapolis, IN 46202-5186. Periodicals postage paid at Indianapolis, IN, and additional mailing offices. **Postmaster:** Send address changes to: *Operative Dentistry*, Indiana University School of Dentistry, Room S411, 1121 West Michigan Street, Indianapolis, IN 46202-5186.

Current pricing for individual, institutional and dental student subscriptions (both USA and all other countries) can be found at our website: www.jopdent.org, or by contacting our subscription manager:

Fax 317/852-3162
E-mail: jmatis@indy.rr.com

Information on single copies, back issues and reprints is also available. Make remittances payable (in US dollars only) to *Operative Dentistry* and send to the above address. Credit card payment (Visa, MasterCard) is also accepted by providing card type, card number, expiration date, and name as it appears on the card.

Contributions

Contributors should study the instructions for their guidance printed in this journal and should follow them carefully.

Permission

For permission to reproduce material from *Operative Dentistry* please apply to *Operative Dentistry* at the above address.

The views expressed in *Operative Dentistry* do not necessarily represent those of the Academies or of the Editors.

Editorial Office

Operative Dentistry
Indiana University School of Dentistry, Room S411
1121 West Michigan Street, Indianapolis, IN 46202-5186
Telephone: (317) 278-4800, Fax: (317) 278-4900
URL: http://www.jopdent.org/

Editorial Staff

Editor: Michael A Cochran
Editorial Assistant/Subscription Manager: Joan Matis
Editorial Associate: Karen E Wilczewski
Associate Editors: Bruce A Matis, Edward J DeSchepper and Richard B McCoy
Managing Editor: Timothy J Carlson
Assistant Managing Editors: Joel M Wagoner and Ronald K Harris

Editorial Board

Editorial

Changes

Change, as the saying goes, is good. Paradoxically, it is a constant in evolution. Change is improvement, innovation and rejuvenation… a chance for fresh ideas and new ways of thinking… an opportunity to rise above past accomplishments and discover better ways to do things.

Change is also unsettling and even frightening, as it alterers the comfortable status quo. It often comes with a considerable learning curve and can be extremely damaging to morale if merely imposed.

Change is not without cost, and should never be done for the sake of change alone. It should be approached with a careful review of history, present functionality and future potential. If it is to be effective, change requires informing and gathering input from all affected.

The *Operative Dentistry* editorial team has tried to make change a constant with your journal. From the beginning of our tenure, we have introduced cosmetic, style and content changes to, hopefully, deliver a better product. We keep looking for ways to make this journal more relevant and appealing to both our readers and contributors. Each issue undergoes continual review from starting the page-setting process to delivery to the publisher. The editorial team in Indiana meets on a monthly basis to discuss problems, errors and ideas for improvement. We also have a day-long session at the end of each publication year to assess our successes and failures and to plan our direction and priorities for the next six issues.

In February, our Editorial Board convenes at the annual Academy of Operative Dentistry meeting to garner input from our distinguished reviewers as to how we can make their job more productive and to solicit their ideas on changes that would enhance *Operative Dentistry*. We have also tried (with only limited success) to solicit feedback and suggestions from you, our readers, and to look for input to increase as time goes on.

Some changes we have made are obvious, while others may have escaped notice or are involved more with the mechanics of publishing than what you see on the printed page. All, however, impact the journal and ultimately the publication you receive bi-monthly. Here are some of the changes we have instituted over the last two-and-a-half years:

- Cover design and many internal style changes
- Size increase from 64 pages per issue to 104 + pages
- Performing all of our own scanning and placing of illustrations to provide complete camera-ready copy to the publisher
- Checking every reference (on Medline) in each manuscript for accuracy
- Initiating a Corporate Sponsorship program to provide additional publication revenue
- Instituting separate publication queues for different types of manuscripts to ensure more timely publication and the ability to include clinical research and clinical techniques/case studies on a regular basis
- Reducing manuscript backlog so that accepted papers are published within 12 months or less of their submission date (this has already resulted in a significant increase in manuscript submission)
- Including color as a viable option for manuscripts that need that type of photographic content
- Adding a number of notable individuals to our already outstanding Editorial Board (see the updated list on the inside front cover of this issue)

Recent changes include revising author information to include the e-mail address of the corresponding author and submitting the entire journal to the publisher electronically (our last issue, 27-3, was the first to be handled in this way). While this submission format will streamline our interaction with the publisher, it was not without transition pains as we struggled with unexplained font changes and spacing aberrations. Fortunately, Allen Press worked diligently with us to correct these problems before the journal reached your hands. This doesn't mean that you won't find occasional mistakes… but we will do our best to minimize errors.

We have also made some new suggestions to authors (see Instructions to Contributors) relative to submitting photographs and illustrations related to both general quality and color.

As you can see, change is a way of life with your journal and will continue to be an underlying force in all of our activities and decision-making processes. We promise, however, that any changes we make will be well thought out and positive. They will be handled with as much input as we can obtain.

The things you have always found enjoyable and informative in *Operative Dentistry* will not be diminished… only improved upon. While change is vital, you can be confident that "the baby will never be thrown out with the bath water."

Michael A Cochran
Editor

©Operative Dentistry, 2002, **27**, 319-324

Effect of Pulp Protection Technique on the Clinical Performance of Amalgam Restorations: Three-Year Results

LN Baratieri • A Machado • R Van Noort
AV Ritter • NMM Baratieri

Clinical Relevance

Results of this study indicate that pulp protection may not be necessary under amalgam restorations made with a high copper, dispersed phase alloy. A longer evaluation is necessary to confirm/reject that observation.

SUMMARY

This study evaluated the influence of the pulp protection technique on clinical performance of amalgam restorations after three years, with particular reference to post-operative sensitivity and secondary caries. One hundred and twenty (120) Class II amalgam restorations (68 premolars, 52 molars; 78 MOD, 42 OD/MO) were placed in 30 participants (four restorations per participant). The restorations were divided into four groups according to the pulp protection technique used: copal varnish; 2% neutral sodium fluoride; adhesive resin and no pulp protection. The parameters evaluated were post-operative sensitivity, staining of the dental structure, tooth vitality, partial or total loss of the restoration and secondary caries. One hundred and eight (108) restorations were available for evaluation after three years. No partial or total loss of restorations had occurred; all teeth were vital, no tooth structure staining or secondary caries was detected in any of the restored teeth. Post-operative sensitivity was observed only in two restorations at baseline and at seven-days. The three-year clinical performance of teeth restored with a high copper dispersed phase amalgam was not

*Luiz Narciso Baratieri, DDS, MS, PhD, professor and head, Department of Operative Dentistry, Universidade Federal de Santa Catarina, Florianópolis, SC–Brazil

Adriana Machado, DDS, MS, private practice, Porto Alegre, RS – Brazil

Richard Van Noort, BSc, DPhil, professor, Operative Dentistry Department, Sheffield University, Sheffield–UK

André V Ritter, DDS, MS, assistant professor, Department of Operative Dentistry, University of North Carolina at Chapel Hill, Chapel Hill, NC; auxiliary professor, Department of Operative Dentistry, Universidade Federal de Santa Catarina, Florianópolis, SC– Brazil

Naira Maria Mascarenhas Baratieri, DDS, MS, PhD, professor, Department of Radiology, Universidade Federal de Santa Catarina, Florianópolis, SC–Brazil

*Reprint request: Rua Presidente Coutinho, 311 – Salas 1001-1004, Florianópolis SC 88015-230–Brazil; e-mail: lbaratieri@hotmail.com

affected by the choice of pulp protection technique.

INTRODUCTION

One of the main goals of a restoration is to prevent microleakage at the tooth-restoration interface. Clinically, marginal leakage can be related to signs and symptoms including sensitivity, marginal staining and recurrent decay and can lead to the failure of the restoration. For amalgam restorations, copal varnish has been widely recommended to avoid migration of metallic ions from the amalgam to the tooth structure, preventing staining, reducing marginal leakage and its consequences, post-operative sensitivity and secondary caries (Fitchie & others, 1990; McComb, Ben Amar & Brown, 1990; Murray, Yates & Williams, 1983). Copal varnish is considered an important dentin sealant in the period between placement of the restoration and formation of amalgam corrosion by-products, which are capable of sealing the tooth-restoration interface.

The kinetics of the initial seal attributed to the varnish and subsequent sealing by the amalgam itself has never been thoroughly elucidated (Newman, 1984). Some reports have demonstrated that cavity varnishes do not produce any benefit to the marginal seal of restorations (Marchiori & others, 1998; Manders, García-Godoy & Barnwell, 1990; Mazer, Rehfeld & Leinfelder, 1988), in both conventional and high-copper amalgam (Andrada, 1982). Furthermore, cavity varnishes have been criticized for providing an uneven film, poor insulation, lack of biologic properties, lack of adhesion between tooth and amalgam and high solubility (Mazer & others, 1988).

Other pulp protection techniques and materials have also been suggested, such as calcium hydroxide cements, zinc oxide and eugenol bases, zinc-phosphate bases, and more. More recently, adhesives have been recommended to seal the tooth preparation, providing pulp protection (Gwinnett & others, 1994; Staninec & Holt, 1988). Amalgam can also be bonded to the tooth preparation, generating secondary retention to the restoration (Staninec, 1989). The medium- and long-term effects of these pulp protection techniques on the clinical performance of amalgam restorations has not been fully investigated.

This study assessed the influence of three different pulp protection techniques on the clinical performance of Class II amalgam restorations over time. The three-year findings are presented.

METHODS AND MATERIALS

Sample Description

Thirty adult patients, ranging in age from 16 to 36 years, were selected for this study. Participants were selected from an original pool of 142 patients from the Federal University of Santa Catarina School of Dentistry, Florianópolis, Brazil. Participants qualified for the study if they required replacement of four defective typical Class II amalgam restorations of moderate size (bucco-lingual isthmus not to exceed 2/3 of the distance between the cusp tips) on vital teeth. In addition, the teeth to be restored needed to have proximal and occlusal contacts in the restoration. The sample for the study consisted of 120 vital teeth (68 premolars and 52 molars) with 78 MOD and 42 OD/MO restorations. Reasons for restoration replacement were secondary caries, marginal failure, bulk fracture, marginal ridge fracture and/or lack of contour (missing proximal contacts).

Restorative Procedures—Experimental Groups

All the preparations were accomplished at water-cooled high-speed with #330 carbide burs. Manual instruments were used to refine the preparations. A caries-detector solution (Caries Detector—Kuraray Company, Ltd, Osaka, Japan) was used to aid in the identification of the carious tissue, whenever necessary. All restorations had proximally contacting surfaces, and the gingival margins were located in enamel. In addition, all the restorations presented occlusal contacts. The remaining dentin thickness (RDT) after tooth preparation/ restoration was determined to be moderately deep. Even though the RDT was not quantitatively determined, all tooth preparations had pulpal and axial walls at least 0.5 mm inside the dentin-enamel junction.

Each of the four preparations in the same participant was protected with a different pulp protection technique prior to placing the amalgam, which consisted of (1) copal varnish, (2) 2% neutral sodium fluoride, (3) a resin adhesive or (4) no pulp protection. The four different pulp protection techniques applied were:

Group 1: All the preparation walls were coated with two layers of copal varnish (Copalite, Cooley & Cooley, Houston, TX 77041, USA);

Group 2: 2% neutral sodium fluoride (DFL, Rio de Janeiro, 22713-0001 Brazil) was applied to all the preparation walls for four minutes, then dried with a blast of air;

Group 3: The resin adhesive system All-Bond 2 (BISCO Inc, Schaumburg, IL 60193, USA) was applied on all enamel and dentin walls according with the manufacturer's instructions and

Group 4: No pulp protection was used, the amalgam was condensed directly onto the freshly-cut enamel and dentin.

All 120 preparations were cut and restored under rubber dam isolation by the same operator (AM) with the same amalgam type (Dispersalloy, Dentsply/Caulk, Milford, DE 19963, USA). After the pulp protection application (Groups 1–3), the amalgam was inserted and carved, the rubber dam was removed and the occlusion adjusted.

Follow-Up Examinations

Evaluations were done at baseline, at seven days and at the end of every subsequent year until the third year after placement of the restorations. Forty-eight hours after placement, all the restored teeth were tested for vitality with tetrafluorethan (–20, Roeko, Langenan, 1150 D-89129, Germany). This appointment represented the baseline for the assessment of post-operative sensitivity. At this same appointment, the restorations were finished and polished. After polishing, the restorations were photographed from the occlusal aspect with X2 magnification. Figures 1a, 2a, 3a and 4a depict representative examples of restorations at the baseline appointment.

Black and white prints were obtained from the color slides and cropped to leave only the occlusal surface of the restoration visible. The photographic documentation allowed for (1) the generation of a photographic archive, (2) the prospective evaluation of the restorations, (3) side-by-side comparison of the baseline vs three-year old restoration, (4) inter-evaluators discussion without the participant being present and (5) more precise statistical analysis.

Bitewing radiographs were obtained for all the teeth, which were used to detect proximal overhangs.

Evaluation of the restorations on every follow-up visit involved visual examination with the aid of a dental explorer and intra-oral mirror. Two independent examiners carried out the clinical examination. Inter-examiner reliability was determined using a statistical method described by Cohen (1969).

At the end of the first, second and third year, respectively 120, 112 and 108 restorations were evaluated by the same examiners. All the teeth were tested for vitality and evaluated clinically at each time point, with attention to marginal integrity, presence/absence of post-operative sensitivity, staining of the dental structure, partial or total loss of the restoration and secondary caries.

At the end of the third year, the photographic records of the restorations were used to evaluate the marginal degradation over that period, using the sequential method proposed (Osborne & others, 1976; Osborne, Binon & Gale, 1980a, Osborne & others, 1980b). Figures 1b, 2b, 3b and 4b show the restorations depicted in Figures 1a, 2a, 3a and 4a, respectively, at the three year recall visit.

As a calibration exercise, prior to the study, the examiners were given a series of photographs of archived amalgam restorations (n=186) that they ranked from best to worst based on the appearance of the restoration margins. The results of the photographic rankings were submitted to a Kruskal-Wallis test that showed no significant difference between the two examiners. The same two examiners then ranked the pictures from the main study from best to worst, and the same statistical analysis was used to determine difference among the four groups.

RESULTS

Baseline

At baseline, all the teeth were vital. Two teeth from Group 3 (adhesive) presented with subtle sensitivity upon biting. Occlusal interference was detected for these restorations, which was removed.

Seven Days

At seven days, all the teeth responded positively to the vitality test and none presented spontaneous pain although two teeth in the adhesive resin group presented sensitivity to cold liquids. Participants in the adhesive resin group reported that the sensitivity was decreasing but it was bearable.

One Year

At the end of the first year, all 120 restorations were reassessed clinically with the aid of photographic images. Not a single fracture was detected, no secondary caries and no stain in the dental structure was present. None of the teeth presented spontaneous pain or pain to cold liquids. All the teeth gave a positive response to the vitality test.

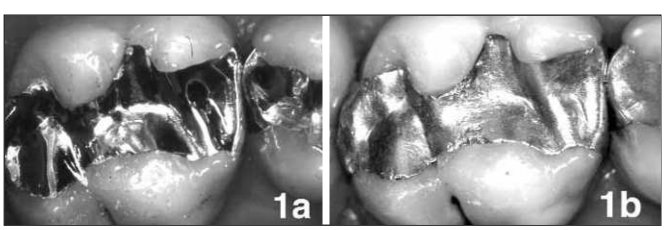


Figure 1. *Representative clinical example of a restoration from Group 1 (cavity varnish) at baseline (a) and at the 3-year recall (b).*

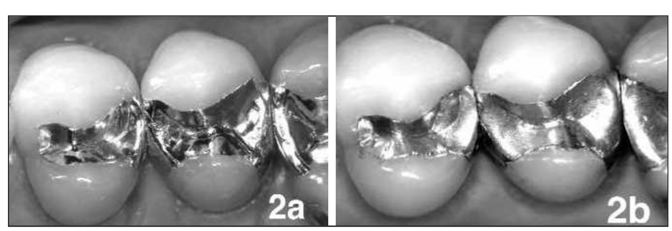


Figure 2. *Representative clinical examples of restorations from Groups 2 (fluoride, #12) and 4 (control, #13) at baseline (a) and at the 3-year recall (b).*

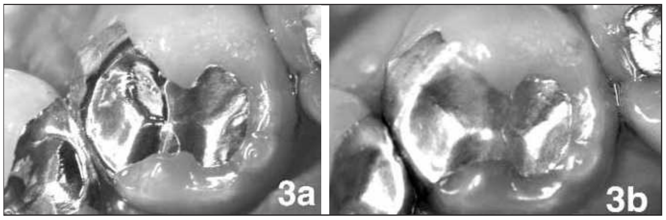


Figure 3. *Representative clinical example of a restoration from Group 3 (adhesive resin) at baseline (a) and at the 3-year recall (b).*

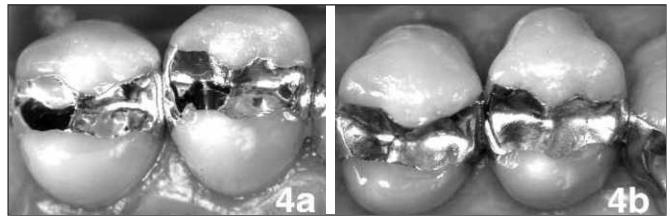


Figure 4. *Representative clinical examples of restorations from Groups 3 (adhesive resin #12 and 4 (control #13) at baseline (a) and at the 3-year recall (b).*

Two Years

At the end of the second year, 112 restorations were re-evaluated clinically and the results were identical to those observed at the end of the first year. All the teeth responded positively to the vitality test. Two participants (eight restorations) missed this evaluation.

Three Years

At the end of the third year, the results from the clinical examination of 108 restorations (three participants did not participate in the third-year evaluation) were identical to those observed at the end of the first and second years. None of the teeth presented spontaneous pain or pain to cold liquids and they all presented a positive response to the vitality test.

Examination of the restorations at three years revealed no statistically significant differences among the four groups regarding marginal integrity, staining of the dental structure, partial or total loss of the restoration and secondary caries regardless of the type of pulp protection technique used.

Inter-examiner reliability tests produced a Kappa score of 0.86, which showed excellent agreement (Cohen, 1969).

DISCUSSION

The use of liners and bases under amalgam restorations has been common practice for many years and continues to be promoted in operative dentistry textbooks (Schwartz & Hilton, 2000; Bayne, Thompson & Taylor, 2001). Bases and liners are believed to provide protection against marginal leakage, affording the tooth pulp protection and post-operative comfort. Nevertheless, current concepts related to the use of liners and bases have been challenged (Hilton, 1996; Leinfelder, 1994; Weiner, Weiner & Kugel, 1996). As knowledge and understanding of the tooth and of dental biomaterials evolves, our approach to the clinical practice should be constantly revisited.

The results of this study indicate that the amalgam-tooth interface seals over time, resulting in low levels of post-operative sensitivity even without the use of a pulp-protecting material. These results agree with other studies (Osborne & others, 1980a; Piperno & others, 1982). Twenty years ago, both Osborne & others, 1980a and Piperno & others had already demonstrated in *in vivo* studies that using bases under amalgam restorations does not contribute to decreased post-operative sensitivity. They hypothesized that amalgams with greater plasticity can be more appropriately condensed and consequently better adapted to the walls and internal angles of the preparation, resulting in tighter margins when compared to regular amalgam alloys.

Previous studies have critically analyzed the use of liners under restorations (Owens, 1996; Pereira & others, 1990). These authors have demonstrated that materials such as calcium hydroxide have a short anti-bacterial effect. In addition, with time, the oral fluids can penetrate through a non-sealed tooth-restoration interface, dissolving partially or totally this pulp-protecting material. This would result in an increased gap at the tooth-restoration interface, increasing the risk of sensitivity and marginal leakage.

Irrespective of the type of pulp protection technique used, not one predisposed the restorations to a poor clinical performance with regard to recurrent caries. The relevance of this finding relates to the fact that recurrent (or secondary) caries is still regarded as the main reason for failure and replacement of amalgam restorations (Mjör & Toffenetti, 2000). Since the factors responsible for primary caries are also responsible for secondary caries, it is inappropriate to solely blame a material or any specific technique for the incidence of recurrent or secondary caries. Even though it was not under the scope of this study to establish the participants' caries risk, the overall caries risk of the sample in this study was considered moderate. It is well known that participants in clinical studies tend to improve their hygiene habits during the evaluation periods of the study. This might have influenced the zero incidences of secondary caries found at the three-year evaluation. Longer evaluation times for this sample may reveal different tendencies or significant differences among the experimental groups.

Poor marginal integrity is another frequently cited reason to replace restorations (Mjör, 1986; Mjör & Toffenetti, 2000). However, Barbakow & others (1988) have shown that 100% of amalgam restoration margins are defective six months after they are placed and therefore poor marginal integrity does not necessarily justify replacement of the restoration. Either periodic recall to monitor the restoration and/or the patient's caries risk or the repair of the margin is preferable to total replacement. The marginal defects that appear in the tooth-restoration interface are mechanically and ecologically similar to occlusal pit and fissure defects. Although occlusal pits and fissures are plaque accumulation sites (Mjör, 1986; Owens, 1996), it is possible to maintain these areas free of caries. The same should be true for ditched amalgam margins. Plaque control is as caries preventive in occlusal pits as it is in ditched margins, provided that these margins are accessible for cleaning (Cardoso, Baratieri & Ritter, 1999). In this study, the photographic evaluation was unable to find differences among the four groups as it relates to marginal degradation, regardless of the inherent marginal breakdown present in all restorations.

The potential advantages for using resin adhesives to bond amalgam to the dental structure are reduced microleakage, reduced incidence of postoperative sensitivity (Staninec & Holt, 1988), reduced marginal fracture (Tarim & others, 1996), increased fracture resistance of the prepared tooth (Eakle, Staninec & Lacy, 1992) and improved retention of the restorations with the potential for preservation of tooth structure during tooth preparation (Staninec, 1989). Although these advantages have obvious merits, their validity still requires confirmation in the clinical setting. A number of concerns have been expressed regarding using adhesive systems in association with amalgam restorations. Recent *in vitro* reports (Boston, 1997; Charlton, Murchison & Moore, 1991; Mahler & Bryant, 1999) indicate that microleakage can be significantly reduced when an adhesive system is used under amalgam restoration in lieu of varnish or no liner. Yet, the same behavior cannot be duplicated *in vivo* when the gingival walls of the proximal box are located on enamel. It is possible that *in vitro* marginal leakage tests are not good predictors of clinical activity (Meiers & Turner, 1998).

This study demonstrated that in a three-year period the use of an adhesive system cannot be justified under typical tooth preparations for amalgam. No significant differences were observed among the restorations that did not receive any type of pulp protection technique and those that were bonded to the dental structure. Similar results were recently reported for another adhesive system (Mahler & Engle, 2000).

Some authors have suggested topical fluoride application under amalgam restorations to minimize the incidence of secondary caries (Alexander, McDonald & Stookey, 1969; Cooley & Barkmeier, 1979; Nixon, Hembree & McKnight, 1978; Peterzen & others, 1990; Stufflebeam & others, 1997). An *in vitro* study (Marchiori & others, 1998) verified that fluoride significantly decreased the performance of amalgam restorations with respect to marginal leakage. In the topical fluoride group, 50% of enamel margins and 100% of dentin margins had maximum leakage scores. This study, however, did not reveal any negative aspects of the use of fluorides, neither was it capable of showing any superiority of that procedure.

Several clinical studies have indicated that the clinical behavior of amalgam restorations observed in the first year of activity is a good predictor of long-term results (Letzel & Vrijhoef, 1984a, 1984b; Mahler & Marantz, 1980; Mjör, 1986; Osborne & others, 1980a, 1980b). This study's results suggest that there are no advantages in the use any pulp protection technique under typical amalgam restorations. It must be emphasized, however, that all the restorations included in this study were replacements of old, failed amalgam restorations. The clinical significance derived from these results might differ from a situation where primary caries is being restored, particularly when related to the physiological condition of the dentin substrates. Dentin can undergo a number of structural changes under restorations, including occlusion of the dentinal tubules, formation of reparative dentin, and more. All these changes can influence the response of the pulp-dentin complex to external stimuli. Hence, when restoring primary caries lesions, the influence of the type of pulp protection technique under amalgam restorations remains to be investigated.

CONCLUSIONS

Based on the results of this study, it can be concluded that the type of pulp protection technique (cavity varnish, adhesive resin or fluoride application) might not influence the clinical performance of teeth restored with moderate sized replacement amalgam restorations after three years of clinical service.

(Received 16 October 2001

References

Alexander WE, McDonald RE & Stookey GK (1969) Effectiveness of a stable 30 percent stannous fluoride solution in the prevention of recurrent dental caries *Journal Indiana Dental Association* **48** 175-179.

Andrada MAC (1982) Estudo comparativo da infiltração marginal em ligas para amálgama enriquecidas ou não com cobre *Odontólogo Moderno* **9** 16-21.

Barbakow F, Geberthuel T, Lutz F & Schupbach (1988) Maintenance of amalgam restorations *Quintessence International* **19** 861-870.

Bayne SC, Thompson JY & Taylor DF (2001) Dental materials in Roberson TM, Heymann HO, Swift Jr EJ (ed), *Sturdevant's*

Art and Science of Operative Dentistry, Fourth Edition, Mosby St Louis 133-234.

Boston DW (1997) Adhesive liner incorporation in dental amalgam restorations *Quintessence International* **28** 49-55.

Cardoso M, Baratieri LN & Ritter AV (1999) The effect of finishing and polishing on the decision to replace existing amalgam restorations *Quintessence International* **30** 413-418.

Charlton DG, Murchison DF & Moore BK (1991) Incorporation of adhesive liners in amalgam: Effect on compressive strength and creep *American Journal of Dentistry* **4** 184-188.

Cohen J (1969) A coefficient of agreement for nominal scales *Education Psychology Measurement* **20** 37-46.

Cooley RL & Barkmeier WW (1979) Reducing recurrent caries with topical stannous fluoride treatment of cavity preparations *General Dentistry* **27** 30-33.

Eakle WS, Staninec M & Lacy AM (1992) Effect of bonded amalgam on the fracture resistance of teeth *Journal of Prosthetic Dentistry* **68** 257-260.

Fitchie JG, Reeves GW, Scarbrough AR & Hembree JH (1990) Microleakage of a new cavity varnish with a high-copper spherical amalgam alloy *Operative Dentistry* **15** 136-140.

Gwinnett AJ, Baratieri LN, Monteiro S Jr & Ritter AV (1994) Adhesive restorations with amalgam: Guidelines for the clinician *Quintessence International* **25** 687-695.

Hilton TJ (1996) Cavity sealers, liners, and bases: Current philosophies and indications for use *Operative Dentistry* **21** 134-146.

Leinfelder KF (1994) Changing restorative traditions: The use of bases and liners *Journal of the American Dental Association* **125** 65-67.

Letzel H & Vrijhoef MM (1984a) Long-term influences on marginal fracture of amalgam restorations *Journal Oral Rehabilitation* **11** 95-101.

Letzel H & Vrijhoef MM (1984b) The influence of polishing on the marginal integrity of amalgam restorations *Journal of Oral Rehabilitation* **11** 89-94.

Mahler DB & Bryant R (1999) Amalgam bonding agents in tensile-shear mode *Journal of Dental Research* **78** Abstract #3410, pg 532.

Mahler DB & Marantz RL (1980) Clinical assessments of dental amalgam restorations *International Dental Journal* **30** 327-334.

Mahler DB & Engle JH (2000) Clinical evaluation of amalgam bonding in class I and II restorations *Journal of the American Dental Association* **131** 43-49.

Manders CA, García-Godoy F & Barnwell GM (1990) Effect of a copal varnish, ZOE or glass ionomer cement bases on microleakage of amalgam restorations *American Journal of Dentistry* **3** 63-66.

Marchiori S, Baratieri LN, de Andrada MA, Monteiro S Jr & Ritter AV (1998) The use of liners under amalgam restorations: An *in vitro* study on marginal leakage *Quintessence International* **29** 637-642.

Mazer RB, Rehfeld R & Leinfelder KF (1988) Effect of cavity varnishes on microleakage of amalgam restorations *American Journal of Dentistry* **1** 205-208.

McComb D, Ben-Amar A & Brown J (1990) Sealing efficacy of therapeutic varnishes used with silver amalgam restorations *Operative Dentistry* **15** 122-128.

Meiers JC & Turner EW (1998) Microleakage of dentin/amalgam alloy bonding agents: Results after 1 year *Operative Dentistry* **23** 30-35.

Mjör IA & Toffenetti F (2000) Secondary caries: A literature review with case reports *Quintessence International* **31** 165-179.

Mjör IA (1986) Buonocore Memorial Lecture. Clinical assessments of amalgam restorations *Operative Dentistry* **11** 55-62.

Murray GA, Yates JL & Williams JI (1983) Effect of four cavity varnishes and a fluoride solution on microleakage of dental amalgam restorations *Operative Dentistry* **8** 148-151.

Newman SM (1984) Microleakage of A copal resin cavity varnish *Journal of Prosthetic Dentistry* **51** 499-502.

Nixon RM, Hembree JH Jr & McKnight JP (1978) *In vitro* effectiveness of topical fluoride under amalgam restorations *Journal of Pedodontics* **2** 107-113.

Osborne JW, Binon PP & Gale EN (1980a) Dental amalgam: Clinical behavior up to eight years *Operative Dentistry* **5** 24-28.

Osborne JW, Leinfelder KF, Gale EN & Sluder TB (1980b) Two independent evaluations of ten amalgam alloys *Journal of Prosthetic Dentistry* **43** 622-626.

Osborne JW, Phillips RW, Gale EN & Binon PP (1976) Three-year clinical comparison of three amalgam alloy types emphasizing an appraisal of evaluation methods used *Journal of the American Dental Association* **93** 784-789.

Owens BN (1996) Initial placement and replacement of amalgam restoration: A respective review *Journal of the Tennessee Dental Association* **76** 37-39.

Pereira JC, Manfio AP, Franco EB & Lopes ES (1990) Clinical evaluation of Dycal under amalgam restorations *American Journal of Dentistry* **3** 67-70.

Peterzen RM, Shaner JW, Stoffers KW & Legan JJ (1990) Effect of stannous fluoride cavity wash on postoperative thermal sensitivity *General Dentistry* **38** 347-349.

Piperno S, Barouch E, Hirsch SM & Kaim JM (1982) Thermal discomfort of teeth related of presence or absence of cement bases under amalgam restorations *Operative Dentistry* **7** 92-96.

Schwartz RS & Hilton TJ (2000) Caries Management and Pulpal Considerations in Schwartz RS, Summit JB, Robbins WR (eds) *Fundamentals of Operative Dentistry. A Contemporary Approach* 2nd ed Quintessence Books Chicago 51-66.

Staninec M (1989) Retention of amalgam restorations: Undercuts versus bonding *Quintessence International* **20** 347-351.

Staninec MA & Holt M (1988) Bonding of amalgam to tooth structure: Tensile adhesion and microleakage test *Journal of Prosthetic Dentistry* **59** 397-402.

Stufflebeam M, Donly KJ & García-Godoy F (1997) Topical fluoride caries inhibition before and after restoration placement *Journal of Dental Research* **76** Abstract #647 pg 94.

Tarim B, Suzuki S, Suzuki S & Cox CF (1996) Marginal integrity of bonded amalgam restorations *American Journal of Dentistry* **9** 72-76.

Weiner RS, Weiner LK & Kugel G (1996) Teaching the use of bases and liners. A survey of North American dental schools *Journal of the American Dental Association* **127** 1640-1645.

©Operative Dentistry, 2002, 27, 325-329

Clinical Evaluation of a Medium-Filled Flowable Restorative Material as a Pit and Fissure Sealant

JT Autio-Gold

Clinical Relevance

A recently introduced medium-filled (46% volume) flowable dental restorative material (CuRay-Match) can be used as a sealant to control occlusal caries on permanent molars. However, additional techniques, such as the use of bonding agent or mechanical cleaning of fissures, might provide better retention rates than those found in this study.

SUMMARY

This clinical study evaluated the retention rate and caries protection of a medium-filled (46% volume) flowable restorative material (CuRay-Match, OMNII Oral Pharmaceuticals, West Palm Beach, FL 33409, USA) compared to an unfilled sealant (Delton, Dentsply Caulk, Milford, DE 19963, USA). Using a half-mouth design, sealants were applied on randomly assigned caries-free first and/or second permanent molars of 32 children ranging in age from 6-11 years. A total of 118 teeth were etched, dried and sealed. Teeth were evaluated at one, six and 18-month intervals. After one month, 52 teeth sealed with unfilled sealant were intact compared with 46 sealed with a medium-filled resin, and after six months, 36 teeth sealed with an unfilled sealant were intact compared with 27 that were sealed with a medium-filled resin. After 18 months, 29 teeth were still fully sealed with an unfilled sealant, whereas 18 were sealed with a medium-filled resin. The difference between the two groups was not statistically significant. Regarding caries development, four teeth sealed with a medium-filled material and five teeth sealed with an unfilled sealant were decayed after 18 months. These results indicate that a medium-filled flowable restorative material did not perform better in retention rate and caries increment when compared to an unfilled conventional sealant. However, the effect of the additional techniques, such as the use of bonding agent and fissurotomy on retention rates should be evaluated in further studies.

Autio-Gold, DDS, assistant professor, Department of Operative Dentistry, University of Florida

*Reprint request: College of Dentistry, Department of Operative Dentistry, PO Box 100415, Gainesville, FL 32610-0415; e-mail: jautio@dental.ufl.edu

INTRODUCTION

Dental sealants have been recognized as an important adjunct to the use of fluorides in preventing dental caries (Weintraub, 1989; Ripa, 1993;). Safety and effectiveness have been demonstrated in more than 25 years of research (Weintraub, 1989; Simonsen, 1991; Ripa, 1993). Findings from the National Institute of Dental and Craniofacial Research (NIDCR) and the National Survey of schoolchildren (1986-1987) showed that almost 90% of the decay was located in the occlusal surfaces of children's teeth (USPHS, 1989). However, according the Third National Health and Nutrition Examination Survey (1988-1991), only about 18.5% of US children ages 5-17 had one or more sealed permanent teeth (Selwitz & others, 1996). Even though most dental professionals have acknowledged the beneficial use of sealants, they are not widely used in practice. Possible reasons for low acceptance of sealants by dentists could be the maintenance repair required for continued effectiveness, lack of insurance coverage, concern for undetected caries underneath the sealants and the expensive recall and maintenance required.

When evaluating visible light-activated sealants, retention, rather than caries inhibition, constitutes the principal criterion for success (Simonsen, 1991; Ripa, 1993). A conclusion drawn from the 1983 National Institute of Health consensus Development Conference on sealants demonstrated that sealants are 100% effective in pits and fissures that remain completely sealed (NIH, 1984). However, studies report the overall sealant loss averages between 5%-10% per year (Straffon & Dennison, 1988; Simonsen, 1991; Ismail & Gagnon, 1995). Also, the early loss of sealants in young patients is a well-recognized clinical phenomenon. Development of sealant material that provides superior retention and caries protection is needed to improve the success of sealants.

The clinical behavior of adhesives and composite materials for dental restorations has significantly improved compared to previously used materials (Jendresen, 1993; Mjör, Dahl & Moorhead, 2000). Important features to consider when selecting composite resins are filler size and amount, as filled resins demonstrate better wear resistance (Powell, 1992). Filler particles are usually a type of glass or silicon dioxide added to the matrix to improve its physical properties. It has been shown that the filled sealants have greater microhardness values than the unfilled (Strang, Cummings & Stephen, 1986a) and that unfilled sealants inhibit more wear than filled commercial sealants (Strang & others, 1986b). Thus, it was postulated in this study that a medium-filled (46% volume of filler) flowable composite material would have better abrasion resistance and thus provide better retention than a conventional unfilled resin.

This clinical study compared the retention rate and caries increment of a medium-filled flowable restorative material (CuRay-Match) to an unfilled sealant (Delton).

METHODS AND MATERIALS

Subjects were recruited from among patients seeking routine dental care at the pediatric dentistry clinic at the University of Florida. Thirty-two children ranging in age from 6-11 years having either first- or second-permanent molars fully erupted and caries-free, were selected to participate in the study. The procedures, possible discomforts or risks and possible benefits were explained to the parents, and their informed consent was obtained prior to the investigation. The research protocol and informed consent forms were reviewed and approved by the University of Florida Health Science Center Institutional Review Board (IRB).

Using a half-mouth design, an unfilled sealant (Delton, Dentsply Caulk, Milford, DE 19963, USA) was applied on randomly assigned upper and lower permanent molars of one side of the mouth and a medium-filled (46% volume of filler) flowable restorative material (CuRay-Match, OMNII Oral Pharmaceuticals, West Palm Beach, Florida 33409, USA) on contra-lateral side. Teeth were isolated with cotton rolls, etched with 37% phosphoric acid for 20 seconds, rinsed for 15 seconds and dried for few seconds until the surface was chalky white. The unfilled sealant material was applied with a Delton applicator. The medium-filled restorative material was applied by using a disposable tip provided by a manufacturer. A cotton tip applicator was used to remove air bubbles and excess sealant in both materials. Both sealants were polymerized for 40 seconds using an Optilux 500 curing light. Careful moisture control was maintained by way of accepted cotton-roll-isolation procedures and a chairside assistant.

One hundred and eighteen teeth from 32 children were sealed at the baseline. After one month, 32 children with 118 sealants were available for evaluation (59 unfilled and 59 medium-filled sealants). After six months, 27 children with 96 sealants (48 unfilled and 48 medium-filled) were evaluated and after 18 months, 26 children with 90 sealants (45 unfilled and 45 medium-filled) were available for evaluation. Further evaluations were not performed due to an excessive dropout rate. The primary reasons for dropouts included family relocation or refusal to continue in the study.

Examinations for retention were conducted using the following criteria: No loss (NL), partial loss (PL) or complete loss (CL). The retention, condition of sealants and caries were evaluated with a dental explorer and by visual inspection.

The methods used for the data analysis were two-way contingency table and a mixed model. Chi-square test was used to compare arch types and caries increments.

RESULTS

The distribution of sealant retention rates after one, six and 18-months is shown in Table 1. After one month, 52 teeth sealed with an unfilled sealant were completely intact compared to 46 sealed with a medium-filled resin. After six months, 36 teeth sealed with an unfilled sealant and 27 sealed with a medium-filled were still intact. After 18 months, 29 were still fully sealed with an unfilled sealant, whereas only 18 were sealed with a medium-filled resin. There were no statistically significant differences between these two sealants after one, six or 18-months. Overall, survival rate seemed to be better for an unfilled sealant after 18 months, but it was not statistically significant (p=0.064). There were no statistically significant differences between sealants in maxillary or mandibular arches or between first and second permanent molars (chi-square).

Regarding caries development, four (9%) teeth sealed with a medium-filled material and five (11%) teeth sealed with an unfilled material developed caries. The difference between unfilled and filled was not statistically significant (chi-square). In all patients, caries developed in teeth with partly or completely lost sealant.

DISCUSSION

This clinical study evaluated the retention of a medium-filled flowable restorative material compared to an unfilled sealant. It has been shown that filled materials have a higher viscosity, less polymerization shrinkage, greater microhardness values and better abrasion resistance than the unfilled materials (Strang & others, 1986a; Strang & others, 1986b), and thus, it was assumed that filled material might provide better retention rates than a conventional unfilled sealant.

This study evaluated sealant loss in young subjects. The most appropriate time for the placement of dental sealants is soon after eruption of the permanent teeth, since recently erupted teeth are immature and less mineralized than teeth exposed to saliva for several years, and early placement of sealants protect teeth from caries development (Waggoner, 1991). However, clinical trials with children are difficult to perform since the success of the follow-up depends on parents' motivation to bring a child to scheduled appointments. This study was concluded after 18 months due to an excessive dropout rate.

The study did not find statistically significant differences between an unfilled and a medium-filled material. At the end of the study, slightly lower retention rates were observed in teeth sealed with a medium-filled material. A similar trend was observed in a study by Handelman & others (1987), where 88% of the teeth sealed with an unfilled resin (Delton, Johnson & Johnson) were completely intact after one year compared to 82% of the teeth that were sealed with the filled resin (Nuva-Cote, LD Caulk Company). At the conclusion of the second year of the Handelman & others study, the rates were 84% (unfilled) and 75% (filled). There were no significant differences between the arches either, which is consistent with this study. In a study by Koch & others (1997), an unfilled resin (Delton, DeTrey/Denstply) was compared to a filled fluoridated sealant (Helioseal F, Vivadent), and the complete retention was 30 out of 31 for Delton and 28 out of 31 for Helioseal F after 12 months. Their results indicated that a filled resin did not show a significant difference when compared to a conventional unfilled resin. The retention and wear resistance was equivocal between the filled and unfilled sealants also in a study by Barrie, Stephen & Kay (1990) and Boksman & others (1993). However, in a study by Rock, Weatherill & Anderson (1990), retention rates of filled sealants were less than the unfilled sealants. Studies comparing the retention of medium-filled flowable materials to conventional, unfilled sealant were not found in the literature. However, this study supports the earlier findings that materials containing fillers do not provide a better retention rate and there are probably other variables than the material, itself, that contribute to the sealant loss.

Few studies have evaluated the influence of tooth isolation on retention rates. In a study by Ganss, Klimek & Gleim (1999), placement under a rubber dam resulted in significantly higher retention rates for both sealants (Helioseal F, Fissurit F), and an improved sealant quality. However, other clinical studies evaluating the influence of the method of moisture control on restoration quality or adhesion reveal contradictory results (Barghi, Knight & Berry, 1991; Heringer, Almeida & Miguel, 1993; Knight & others, 1993; Smales, 1993). Numerous studies have shown that sealant retention rates are comparable when performed using a rubber dam or cotton-roll isolation (Eidelman, Fuks & Chosack, 1983; Straffon, Dennison

Table 1: *Distribution of Retention Rates*

	Unfilled (Delton)			Medium-Filled (CuRay-Match)		
	1-month	6-month	18-month	1-month	6-month	18-month
NL	52 (88.1%)	36 (75.0%)	29 (64.4%)	46 (78.0%)	27 (56.3%)	18 (40.0%)
PL	5 (8.5%)	6 (12.5%)	8 (17.8%)	9 (15.3%)	11 (22.9%)	12 (26.7%)
CL	2 (3.4%)	6 (12.5%)	8 (17.8%)	4 (6.8%)	10 (20.8%)	15 (33.3%)
Total	59	48	45	59	48	45

NL = No Loss; PL = Partial Loss; CL - Complete Loss

& More, 1985; Waggoner & Siegal, 1996). The sealants in this study were placed in dry field conditions with cotton-roll isolation and a chair-side assistant and no saliva contamination was observed.

Few studies have evaluated the use of bonding agents as an option to improve retention rates. Hitt & Feigal (1992) first reported the benefits of adding a dentin-bonding agent between the etched enamel and the sealant as a way of optimizing bond strength. Other studies have confirmed the benefits of bonding agents under sealants (Choi & others, 1997; Fritz, Finger & Stean, 1998) and improveed short-term clinical success (Feigal, Hitt & Splieth, 1993). A recent study by Feigal & others (2000) showed that single-bottle bonding agents improve sealant retention, yielding half the usual risk of failure for occlusal sealants. The effect of bonding agent to improve the retention rate of medium-filled materials should be considered in future studies.

Several studies have evaluated techniques for cleaning fissures to prepare them for etching and sealing to provide improved sealant penetration and effectiveness. Mechanical preparation has been suggested to provide better access to deeper fissures, thus enabling removal of debris and deeper sealant penetration (Feldens & others, 1994). Further studies should evaluate retention of a medium-filled flowable restorative material in minimally invasive preparations compared to conventional sealants.

Sealant surface characteristics are also important to consider when evaluating filled materials because rough surfaces and margins contribute to plaque retention and caries development. Koch & others (1997) showed that filled materials compared to non-filled materials displayed significantly poorer marginal adaptation. In this study, medium-filled sealants with partial loss showed some slight steps or ledges when probed. However, the caries protection was the same regardless of the material used.

The early loss of sealants in young patients is a well-recognized clinical phenomenon. In this study, the sealant failure rate after one-month was 17%, which was expected due to the young age of the subjects and the newly erupted teeth. Futatsuki & others (1995) found that the rate of partial and complete sealant loss on the observed surfaces was 14.4% at the three-month recall, with further loss of 7.0 % between three- and six-month recalls. Early loss is believed to result from fracture caused by a failure of adhesion between sealant and tooth enamel, rather than a wearing away of the sealant material. The presence of unetched areas after acid etching could be a major cause of a failure of adhesion. Poor marginal adaptation and unetched areas could be a major cause for early loss of sealants and further long-term studies are needed to evaluate this aspect with flowable materials.

CONCLUSIONS

An unfilled sealant material performed slightly better in retention when compared to a medium-filled flowable restorative material, but the difference was not statistically significant. Both materials studied presented similar results in caries protection. The retention rate was not influenced by arch or tooth type.

This study suggests that flowable restorative materials could be used as sealants. However, due to the variation in viscosity, composition and physical properties of the various flowable materials available, they should be tested in future studies before general recommendation regarding their use as sealants can be made. Also, factors other than composition of material might contribute to sealant performance. The use of additional techniques to improve retention of sealants, including bonding agents and mechanical cleaning of fissures, should be evaluated in further long-term studies.

Acknowledgement

This study was funded by OMNII Oral Pharmaceuticals, West Palm Beach, Florida 33409, USA. Staff assistance provided by the Pediatric Dental Clinic, University of Florida, is gratefully acknowledged.

(Received 1 November 2001

References

Barghi N, Knight GT & Berry TG (1991) Comparing two methods of moisture control in bonding to enamel: A clinical study *Operative Dentistry* **16(4)** 130-135.

Barrie AM, Stephen KW & Kay EJ (1990) Fissure sealant retention: a comparison of three sealant types under field conditions *Community Dental Health* **7(3)** 273-277.

Boksman L, McConnell RJ, Carson B & McCutcheon-Jones EF (1993) A 2-year clinical evaluation of two pit and fissure sealants placed with and without the use of a bonding agent *Quintessence International* **24(2)** 131-133.

Choi JW, Drummond JL, Dooley R, Punwani I & Soh JM (1997) The efficacy of primer on sealant shear bond strength *Journal of Pediatric Dentistry* **19(4)** 286-288.

Eidelman E, Fuks AB & Chosack A (1983) The retention of fissure sealants: Rubber dam or cotton rolls in private practice *Journal of Dentistry for Children* **50(4)** 259-261.

Feigal RJ, Hitt J & Splieth C (1993) Retaining sealant on salivary contaminated enamel *Journal of the American Dental Association* **124(3)** 88-97.

Feigal RJ, Musherure P, Gillespie B, Levy-Polack M, Quelhas I & Hebling J (2000) Improved sealant retention with bonding agents: A clinical study of two-bottle and single-bottle systems *Journal of Dental Research* **79(11)** 1850-1856.

Feldens EG, Feldens CA, de Araujo FB & Souza MA (1994) Invasive technique of pit and fissure sealants in primary molars: A SEM study *Journal of Clinical Pediatric Dentistry* **18(3)** 187-190.

Fritz UB, Finger WJ & Stean H (1998) Salivary contamination during bonding procedures with one-bottle adhesive system *Quintessence International* **29(9)** 567-572.

Futatsuki M, Kubota K, Yeh YC, Park K & Moss S (1995) Early loss of pit and fissure sealant: A clinical and SEM study *The Journal of Clinical Pediatric Dentistry* **19(2)** 99-104.

Ganss C, Klimek J & Gleim A (1999) One-year clinical evaluation of the retention and quality of two fluoride-releasing sealants *Clinical Oral Investigations* **3** 188-193.

Heringer M, Almeida MA & Miguel JA (1993) Direct bond brackets: Cotton roll versus rubber dam isolation *The Angle Orthodontist* **63** 231-234.

Handelman SL, Leverett DH, Espeland M & Curzon J (1987) Retention of sealants over carious and sound tooth surfaces *Community Dentistry and Oral Epidemiology* **15(1)** 1-5.

Hitt JC & Feigal RJ (1992) Use of a bonding agent to reduce sealant sensitivity to moisture contamination: An *in vitro* study *Journal of Pediatric Dentistry* **14(1)** 41-46.

Ismail AI & Gagnon PA (1995) A longitudinal evaluation of fissure sealants applied in dental practices *Journal of Dental Research* **74(9)** 1583-1590.

Jendresen M (1993) Clinical behavior of 21st-century adhesives and composites *Quintessence International* **24(9)** 659-662.

Knight GT, Berry TG, Barghi N & Burns TR (1993) Effects of two methods of moisture control on marginal microleakage between resin composite and etched enamel: A clinical study *International Journal of Prosthodontics* **6(5)** 475-479.

Koch MJ, García-Godoy F, Mayer T & Staehle HJ (1997) Clinical evaluation of Helioseal F fissure sealant *Clinical Oral Investigations* **1(4)** 199-202.

Mjör IA, Dahl JE & Moorhead JE (2000) Age of restorations at replacement in permanent teeth in general dental practice *Acta Odontologica Scandinavia* **58(3)** 97-101.

National Institute of Health (NIH) (1984) Consensus development conference statement: Dental sealants in the prevention of tooth decay *Journal of Dental Education* **48(2 Supplement)** 126-131.

Powell LV (1992) Composite-resin materials and techniques in dentistry *Current Opinion in Dentistry* **Mar 2** 128-136.

Ripa LW (1993) Sealants revisted: An update of the effectiveness of pit-and-fissure sealants *Caries Research* **27(Supplement 1)** 77-82.

Rock WP, Weatherill EDT & Anderson RJ (1990) Retention of fissure sealant resins. The effects of etching agent and curing method. Results over 3 years *British Dental Journal* **168(8)** 323-325.

Selwitz RH, Winn DM, Kingman A & Zion GR (1996) The prevalence of dental sealants in the US population: Findings from NHANES III, 1988-91 *Journal of Dental Research* **75 (Special No)** 652-660.

Simonsen RJ (1991) Retention and effectiveness of dental sealants after 15 years *Journal of the American Dental Association* **122(11)** 34-42.

Smales RJ (1993) Rubber dam usage related to restoration quality and survival *British Dental Journal* **174(9)** 330-333.

Straffon LH, Dennison JB & More FG (1985) Three-year evaluation of sealant: Effect of isolation on efficacy *Journal of the American Dental Association* **110(5)** 714-717.

Straffon LH & Dennison JB (1988) Clinical evaluation comparing sealant and amalgam after 7 years: Final report *Journal of the American Dental Association* **117(6)** 751-755.

Strang R, Cummings A & Stephen KW (1986a) Laboratory studies of visible-light cured fissure sealants: Setting times and depth of polymerization *Journal of Oral Rehabilitation* **13(4)** 305-310.

Strang R, Cummings A, Stephen KW & McMenemy P (1986b) Further abrasion resistance and bond strength studies of fissure sealants *Journal of Oral Rehabilitation* **13(3)** 257-262.

Waggoner WF (1991) Managing occlusal surfaces of young permanent molars *Journal of the American Dental Association* **122(11)** 72, 74, 76.

Waggoner WF, Siegal M (1996) Pit and fissure sealant application: Updating the technique *Journal of the American Dental Association* **127(3)** 351-361.

Weintraub JA (1989) The effectiveness of pit and fissure sealants *Journal of Public Health Dentistry* **49(5 Spec No)** 317-330.

US Public Health Service, USPHS (1989) Oral Health of United States children: The national survey of dental caries in US schoolchildren, 1986-1987: NIH pub #89-2247, Bethesda, MD.

©Operative Dentistry, 2002, **27**, 330-342

Histopathologic Study on Pulp Response to Single-Bottle and Self-Etching Adhesive Systems

VO Medina, III • K Shinkai • M Shirono
N Tanaka • Y Katoh

Clinical Relevance

Direct pulp capping with some adhesive resins could result in pulp healing comparable to calcium hydroxide capping. However, a delay in the initiation and completion of dentin bridge formation should be expected.

SUMMARY

This study compared the pulp response to seven adhesive resins (three single-bottle and four self-etching primers) and their companion resin composite systems with a commercial calcium hydroxide material when applied to exposed monkey pulps. The control group was capped with Dycal (DY), while the experimental groups were capped with one of the following adhesive resin systems: AQ Bond (AQ), Single Bond (SB), Imperva Fluorobond (IF), One Step (OS), Prime&Bond NT (PBNT), Perme Bond F (PBF) and One-up Bond F (OBF). Histopathologic evaluation of pulp tissue disorganization, inflammatory cell infiltration, reparative dentin formation and bacterial penetration at the 3rd, 30th and 90th post-operative days was done using light microscopy. Data were analyzed using the Kruskal-Wallis test followed by the Least Significant Difference Test to determine differences between the control group and the experimental groups at each observation period. The correlation of inflammatory cell infiltration and bacterial presence was investigated by the Kendall correlation analysis. All tests were performed at a 95% level of confidence. The pulpal responses of groups DY, SB, OS, PBF and OBF were generally characterized by none-to-mild pulp tissue disorganization and inflammatory cell infiltration. Also, initiation of reparative dentin formation was found earlier in Group DY, resulting in more complete dentin bridges at the 30- and 90-day observation periods. Groups AQ, IF and PBNT had significantly more inflammatory cell infiltration and a lower incidence of reparative dentin formation than Group DY. A significant correlation was detected between inflammatory cell infiltration and the presence

*Vicente O Medina III, DDM, associate professor, Department of Clinical Dental Health Sciences, College of Dentistry, University of the Philippines Manila

Koichi Shinkai, DDS, PhD, associate professor, Department of Operative Dentistry, School of Dentistry at Niigata, The Nippon Dental University, Japan

Manabu Shirono, DDS, PhD, instructor, Department of Operative Dentistry, School of Dentistry at Niigata, The Nippon Dental University, Japan

Norihiro Tanaka, DDS, PhD, instructor, Department of Operative Dentistry, School of Dentistry at Niigata, The Nippon Dental University, Japan

Yoshiroh Katoh, DDS, PhD, professor and chair, Department of Operative Dentistry, School of Dentistry at Niigata, The Nippon Dental University, Japan

*Reprint request: Padre Faura, Ermita, Manila 1000, Philippines; e-mail: giamed@hotmail.com

of bacteria. It is concluded that the pulp response to SB, OS, PBF and OBF is not significantly different from the calcium hydroxide preparation. However, calcium hydroxide capping resulted in a higher incidence and faster rate of reparative dentin formation.

INTRODUCTION

Calcium hydroxide has been regarded by many as an excellent direct pulp capping agent since its introduction by Hermann in 1920 (Hermann, 1920). It owes its popularity to two factors: its ability to induce reparative dentin formation more consistently than any other material (Baume & Holz, 1981; Lim & Kirk, 1987) and its ability to contribute to pulp healing by being bactericidal, which has been attributed to its high alkalinity (McWalter, El-Kafrawy & Mitchell, 1973). Notwithstanding its success for several decades, the search for a better direct pulp capping material continues. This is because of the clinical dissolution of calcium hydroxide (Kidd, 1976), the recurrence of pulp inflammation and necrosis (Cox & others, 1985) and the presence of tunnel defects in dentin bridges formed against calcium hydroxide (Cox & others, 1996b). Some recent research has focused on antioxidant enzymes (Alacam & others, 2000), hydroxyapatite (Hayashi & others, 1999; Higashi & Okamoto, 1996), mineral trioxide aggregate (Ford & others, 1996), chlorhexidine (Thomas & others, 1995), bone morphogenetic protein (Gao & others, 1995), tetracalcium phosphate base cement (Yoshimine & Maeda, 1995), alpha calcium phosphate with antibacterial drugs (Yoshiba, Yoshiba & Iwaku, 1995) and hyaluronic acid (Sasaki & Kawamata-Kido, 1995).

Numerous research has also been conducted on adhesive resins mainly because of their ability to provide a biologic seal against microleakage (Cox & Suzuki, 1994; Fujitani, Inokoshi & Hosoda, 1992; Goracci, Mori & Bazzucchi, 1995; Kitasako & others, 2000; Inoue & Shimono, 1992; Tsuneda & others, 1995; White & others, 1994). This seal is considered very important because of findings that the pulpal inflammatory process was always associated with bacteria under restorations (Brännström & Nyborg, 1972) and that pulp healing is directly related to the capacity of the capping agent to prevent microleakage and exclude bacteria (Cox & others, 1987). These findings suggest that pulp healing and dentin bridge formation is not dependent on material-specific factors. This concept is supported by the results of recent studies showing pulp healing in resin-capped teeth when bacteria and microleakage are eliminated (Kitasako, Inokoshi & Tagami, 1999; Tarim & others, 1998; Olmez & others, 1998; Cox & others, 1998; Akimoto & others, 1998; Cox & others, 1996a; Otsuki & others, 1997; Onoe, Inokoshi & Yamada, 1996; Heitmann and Unterbrink, 1995). On the other hand, there are studies that showed poor results with adhesive resin-capped teeth even in the absence of bacteria (Pereira, Segala & Costa, 2000; Costa & others, 2001; do Nascimento & others, 2000; Pameijer & Stanley, 1998; Hebling, Giro & Costa, 1999; do Nascimento Fontana & Costa, 1998). Gwinnett & Tay (1997) also reported that the presence of persistent chronic inflammation in resin-capped teeth interfered with dentin bridge formation. It is, therefore, evident that currently, there are two contrasting views on the effect of adhesive resins on exposed pulps that has not been resolved even during the most recent conference on the Pulp-dentin complex, where two papers (Costa, 2001; Katoh, 2001) with opposing results were presented. To better understand this complex issue, our laboratory has conducted several studies on human teeth (Katoh, 1993; Katoh, 1997; Katoh, Kimura & Inaba, 1999) and monkey teeth (Ebihara & Katoh, 1996; Suzaki & Katoh, 1997; Katoh & others, 1997a; Shinkai & others, 1997; Jin, Shinkai & Katoh, 2000; Tanaka & Katoh, 2001) to test the biocompatibility of adhesive resins. Most of these studies observed good pulpal reactions to adhesive resins but none had simultaneously tested the newest generation of adhesive resin systems as direct pulp capping agents.

This study compared the pulp response to seven adhesive resins (three single-bottle and four self-etching primers) and their companion resin composite systems with that of a commercial calcium hydroxide material when applied to exposed monkey pulps.

METHODS AND MATERIALS

Materials

Table 1 lists the composition, application steps, lot numbers and manufacturers of the adhesive resin systems.

Specimen Preparation

A total of 120 teeth in four adult *Macaca fascicularis* monkeys were used in this study. They were randomly assigned to eight groups with five teeth per observation period. All the teeth were scaled and polished with a rubber cup and prophylaxis paste two weeks before and immediately prior to the operative procedures. The monkeys were sedated by IM injection of Ketamine hydrochloride (Ketalar, Lot #M64J, Sankyo Pharmaceutical Co, Tokyo 140-0005, Japan) and each tooth was anesthetized by infiltration with 2% lidocaine hydrochloride with 1:80,000 epinephrine (Xylocaine, Fujisawa Co, Osaka 541-0045, Japan). The teeth were isolated with sterile cotton roll and gauze. Class V cavities with beveled enamel margins were prepared with a 440 diamond point (Shofu Inc, Kyoto 605-0983, Japan) in a high-speed handpiece under copious water spray. The pulps were then exposed with a #1 steel bur (Hager & Meisinger GmbH, D40018 Dusseldorf, Germany), in a low-speed handpiece also under copious water spray. New diamond points and steel burs were used after every four teeth. Hemostasis was achieved

Table 1: *Adhesive Resin Systems Used in the Study*

Adhesive Resin	Composition	Application Steps*	Lot #	Manufacturer
Group 2: AQ Bond (self-etching primer)	AQ Bond: water, acetone, 4- META, UDMA, photoinitiator, stabilizer E-ponge: salt of p-toluenesulfinic acid	e, e, e, f, g	99005 990706	Sun Medical Co, Ltd 571-2 Furutaka-cho Moriyama, Shiga 524, Japan
Group 3: Single Bond (single-bottle adhesive)	Etchant: 35% Phosphoric acid gel, 5% colloidal silica, thickener, antioxidants, color, water Adhesive: Bis-GMA, HEMA, water, ethanol, polyalkenoic acid copolymer	a, b, c2, e, e, f, g	9AB 9AT	3M Dental Products, St Paul MN 55144, USA
Group 4: Imperva Fluorobond (self-etching primer)	Etchant: 7% phosphoric acid Primer A: water, acetone, initiator Primer B: 4-AET, 2-HEMA, 4-AETA, FB Bond: 4-AET, HEMA, UDMA, glass-ionomer filler, microfiller	d, (wait 20 seconds), g	109804 109846 109859 119853	Shofu Inc 11 Kamitakamatsu-cho, Fukuine Higashiyama-ku, Kyoto 605-0983, Japan
Group 5: One Step (single-bottle adhesive)	Uni-Etch etchant: 32% phosphoric acid Adhesive: BPDM, Bis-GMA, HEMA, acetone, photoinitiator	a, b, c1, e, e, f, g, e, e, f, g, e, f	9800001174 9800001814	BISCO Inc 1100 W Irving Park Rd Schaumburg, IL 60193, USA
Group 6: Prime&Bond NT (single-bottle adhesive)	Etchant: 36% Phosphoric acid gel Adhesive: PENTA, UDMA, cetylamine hydrofluoride, acetone, nanofiller, Resin R5-62-1, T-resin, D-resin, initiator	a, b, c2, e, (wait 20 seconds), f, g	9809001214 9809000655	Dentsply/De Trey GmbH D-78467 Konstanz Germany
Group 7: Perme Bond F (self-etching primer)	Primer: Methacryloxyethyl pyrophosphate, 2-HEMA, Ethanol, water, camphorquinone, Ethyl P-N,N-Dimethylaminobenzoate Bonding agent: Penta(methacryloxyethyl-dioxy) Cyclophosphazene Florid, Ethyl P N,N-Dimethylaminobenzoate, 1,6-Dimethacrylethyloxy Carbonilamino Trimethylhexane, 2-HEMA, Pyromellitic Diethyl Methacrylate	d, wait 20 seconds, f, e, f, g	980911 980911	Degussa AG Geschäftsbereich Dental Postfach 1364 D-63403 Hanau Germany
Group 8: One-up Bond F (self-etching primer)	Bonding agent A: MAC-10, photoinitiator, methacryloyloxyalkyl acid phosphate, multi-functional methacrylic monomers Bonding agent B: MMA, HEMA, water, F-deliverable micro-filler, photoinitiator	d, wait 20 seconds, g	001 501	Tokuyama Corp 3-1 Shibuya 3-chome Shibuya-ku, Tokyo 150-8383 Japan

**Procedures: (a) etch enamel and dentin; (b) rinse etchant; (c1) blot dry; (c2) dry with mild air; (d) apply primer; (e) apply bonding agent/adhesive; (f) gently air dry primer or adhesive; (g) light-cure.*

Abbreviations: 4-META = 4-methacryloxyethyl trimellitate anhydride; UDMA = urethane dimethacrylate; Bis-GMA = bis-glycidyl- dimethacrylate; HEMA = hydroxyethylmethacrylate; 4-AET = 4-acryloxyethyltrimellitic acid; 2-HEMA = 2-

hydroxyethylmethacrylate; 4-AETA = 4- acryloxyethyltrimellitate anhydride; BPDM = bisphenyl-dimethacrylate;

MMA = methylmethacrylate

by flooding the cavity with 10% NaOCl (AD Gel, Lot #000261, Kuraray Dental Co, Okayama 710-8622, Japan) for five minutes. Reapplication of AD Gel was done in the pulps that continued to bleed. This was followed by alternate irrigation with 3% hydrogen peroxide and 6% sodium hypochlorite three times to remove dentin chips (Katoh, Kidokoro & Kurosu, 1978). The cavity was then rinsed with normal saline three times, gently air dried or kept moist and the cavity was restored with the appropriate adhesive resin and composite system. The control group was capped with Dycal (Lot #990628, Dentsply/Caulk, Milford, DE 19963-0359, USA) and restored with a resin modified glass-ionomer restorative material, Vitremer (Lot #19990817, 3M Dental Products, St Paul, MN 55144, USA). All the materials were applied according to the manufacturer's instructions (Table 1). The adhesive resins and composite restorative materials were light cured with a Lightel II light curing unit that was regularly checked (Curing Radiometer Model 100, Demetron Research Corp, Danbury, CT 06810, USA) to ensure an output greater than 400 mW/cm^2.

The monkeys were sacrificed 3, 30 and 90 days after the pulp capping procedures with an overdose of Ketalar. Teeth were fixed by perfusion fixation with 10% buffered formalin. The maxillae and mandibles were removed with a bone saw. The teeth (minus the apical third) and surrounding bone were separated from the jawbones and post-fixed for another seven days. They were decalcified with 10% EDTA at room temperature for two months. They were then dehydrated in ascending grades of ethanol and embedded in paraffin. Serial sections of 6-8 µm thickness were cut using a sliding microtome and alternately stained with Mayer's H & E, Hucker-Conn bacterial stain and van

Gieson stain for collagen. Single blind evaluation of the histologic features was performed using light microscopy. The following parameters were evaluated: pulp tissue disorganization; inflammatory cell infiltration; reparative dentin formation and bacterial penetration. The findings were graded using the following criteria.

Evaluation Criteria

Pulp Tissue Disorganization

1- Normal or almost normal tissue morphology.

2- Odontoblast layer disorganization but deep part of the pulp is normal.

3- Loss of general tissue morphology.

4- Necrosis in the coronal third or more of the pulp.

Inflammatory Cell Infiltration

1- No or a few scattered inflammatory cells present in the pulp.

2- Mild acute/chronic cell lesion.

3- Moderate inflammatory cell lesion seen as an abscess or dense stained infiltrate of polymophonuclear leucocytes, histiocytes and lymphocytes in one-third or more of the coronal pulp and/or the mid-pulp.

4- A severely infected to necrotic pulp or lack of tissue in half or more of the pulp.

Reparative Dentin Formation

1- No dentin bridge formation.

2- Initial dentin bridge formation extending not more than half of exposure site.

3- Partial/incomplete dentin bridge formation extending more than half but not completely closing exposure site.

4- Complete dentin bridge formation.

Bacterial Penetration

1- Absence of stained bacterial profiles in any of the sections.

2- Positive bacterial staining profiles along the coronal or apical walls of the cavity.

3- Positive bacterial staining profiles within the cut dentinal tubules or axial wall of the cavity.

4- Positive stained bacterial profiles within the dental pulp.

In addition, the following histologic features were recorded: hemorrhage, dentin chips (location, size and number) and reactionary (irritation) dentin formation.

The diameters of the exposed area were measured with a stereomicroscope (Nikon Measurescope Model II, Nikon Co, Tokyo 110-8831, Japan) and the widest dimension was recorded as the exposure size of the specimen.

Statistical Analysis

The results of the histopathologic evaluation were statistically analyzed by Kruskal-Wallis Test (non-parametric ANOVA) for differences among the groups at each observation period and the Least Significant Difference Test between mean ranks for differences between the control and each of the experimental groups at $p=0.05$. When the difference between the mean of the control group and the mean of one of the

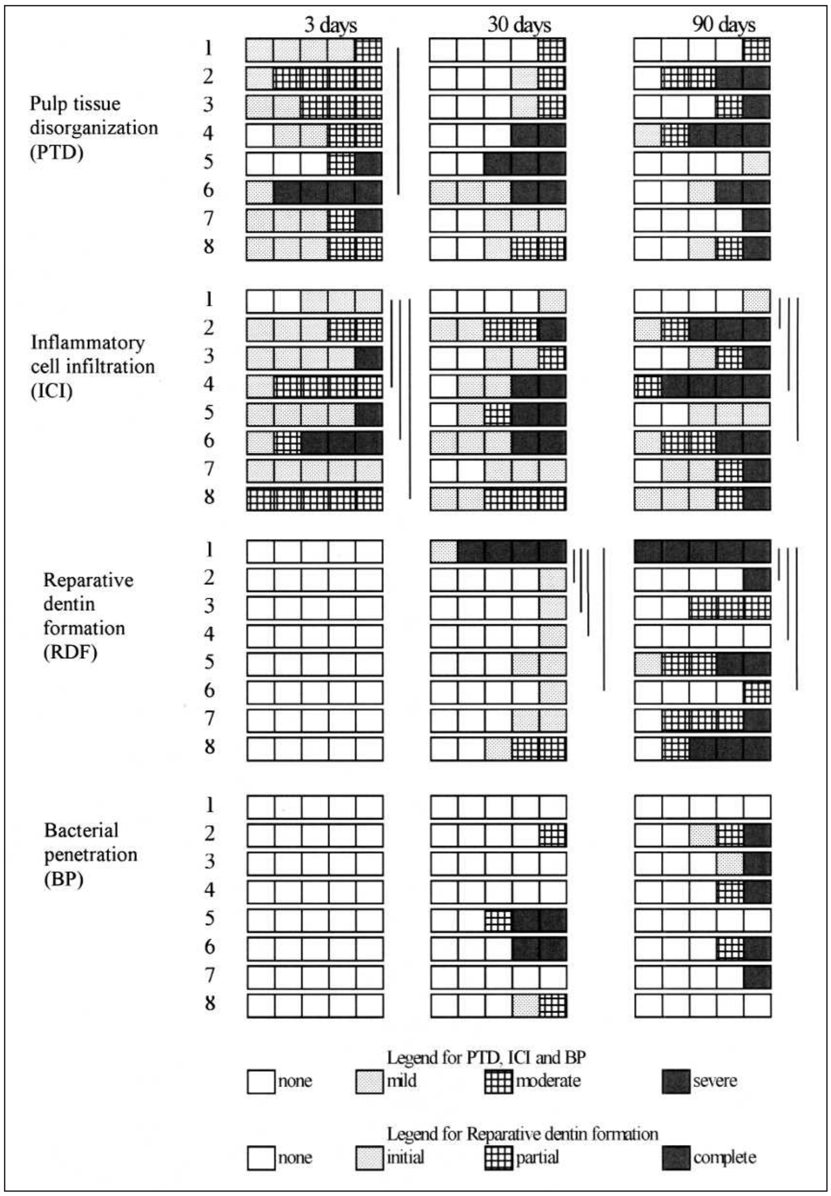


Figure 1. *Results of histopathologic evaluation. Vertical lines indicate that groups at both ends are significantly different (LSD=17.597).*

Table 2: *Results of the Histopathologic Evaluation*

Groups Capping & Restorative Material	Days	Total Teeth	Pulp Tissue Disorganization				Inflammatory Cell Infiltration				Reparative Dentin Formation				Bacterial Penetration				Diameter of Exposure Size Mean(SD) in mm
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Group 1	3	5		4	1		2	3			5				5				0.63(0.31)
Dycal	30	5	4		1		4	1				1		4	5				0.79(0.24)
Vitremer	90	5	4		1		4	1						5	5				0.85(0.24)
Group 2	3	5		1	4			3	2		5				5				0.68(0.19)
AQ Bond	30	5	3	1	1			2	2	1	4	1			4		1		0.57(0.10)
Metafil C	90	5	1		2	2		1	1	3	4			1	2	1	1	1	0.90(0.18)
Group 3	3	5		2	3			4		1	5				5				0.63(0.15)
Single Bond	30	5	3	1	1		2	2	1		4	1			5				0.66(0.10)
Z100	90	5	3		1	1	2	1	1	1	2		3		3	1		1	0.84(0.08)
Group 4	3	5	1	2	2			1	4		5				5				0.56(0.13)
Imperva Fluorobond	30	5	3			2	1	2		2	4	1			5				0.67(0.09)
Lite-Fil IIA	90	5		1	1	3			1	4	5				3		1	1	0.91(0.22)
Group 5	3	5	3		1	1		4		1	5				5				0.59(0.15)
One Step	30	5	2			3	1	1	1	2	3	2			2		1	2	0.77(0.37)
Ælitefil	90	5	4	1			2	3				1	2	2	5				0.81(0.09)
Group 6	3	5		1		4		1	1	3	5				5				0.61(0.23)
Prime&Bond NT	30	5		3		2		3		2	4	1			3			2	0.69(0.28)
Spectrum TPH	90	5	2	1		2		1	2	2	4		1		3		1	1	0.74(0.21)
Group 7	3	5		3	1	1		5			5				5				0.71(0.19)
Perme Bond F	30	5	2	3			2	3			3	2			5				0.60(0.14)
Degufill Mineral	90	5	4			1	1	2	1	1	1		3	1	4			1	0.75(0.17)
Group 8	3	5		3	2				5		5				5				0.65(0.20)
One-up Bond F	30	5	2	1	2			2	3		2	1	2		3	1	1		0.61(0.11)
Palfique Estelite	90	5	2	1	1	1		3	1	1	1		1	3	5				0.73(0.24)

experimental groups exceeded the least significant difference (calculated to be 17.597), the difference was considered statistically significant. The correlation between inflammatory cell infiltration and bacterial presence was investigated by Kendall Correlation Analysis ($p<0.05$).

RESULTS

The results of the histopathologic evaluation are summarized in Figure 1 and Table 2. Figures 2-10 are representative histopathologic photographs of the control group, adhesive groups with acceptable results and adhesive groups with unacceptable results.

There was no significant difference among the pulp exposure sizes of the groups (F=0.28; df=7; p=0.96).

Pulp Tissue Disorganization

After three days, the control group and all adhesive resin groups except Group 6 exhibited mild-to-moderate pulp tissue disorganization. Kruskal-Wallis Test for pulp tissue disorganization data revealed a significant difference between groups (KW Chi^2 =13.99, p=0.05). Group 6 had four teeth with severe tissue disorganization and this result was significantly different from the control group. The specimens of this group also presented with a peculiar histologic picture that was not observed in the other groups. There were a considerable number of red blood cells seen in four out of five specimens. A review of our notes disclosed that the hemorrhage of these teeth were successfully controlled with a single application of AD Gel and there was no bleeding noted prior to or after the application of the etchant. It is possible that a component of this system, with the help of acetone, diffused into and impeded proper hemostasis since the extravasated RBCs were not limited to the exposure site nor its surroundings but also at the central part of the pulp (Figure 11).

After 30 days, there was no statistically significant difference between the control and the adhesive resin groups. Most of the groups showed none-to-mild disorganization. Groups 4, 5 and 6 had a total of seven cases among them with persistent moderate and severe disorganization.

After 90 days, there was also no significant difference between the control and adhesive resin groups. Most of

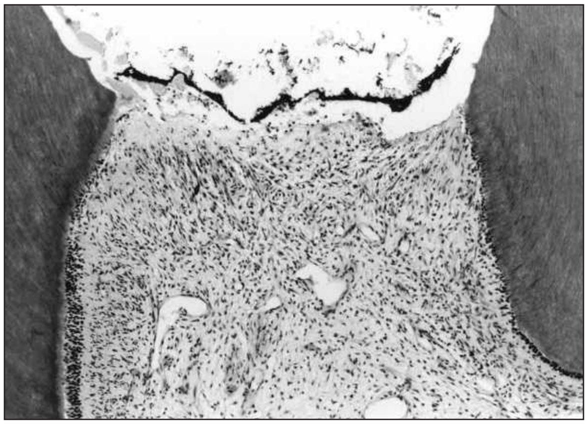


Figure 2. *Histologic picture of a tooth capped with Dycal at the 3rd post-operative day. The black material at the surface is the calcium hydroxide capping material. A thin necrotic zone is visible and below it are numerous fibroblasts. There is mild pulp tissue disorganization, and a few chronic inflammatory cells may be seen at the lower right portion. (H & E, x100, 5-27-13R).*

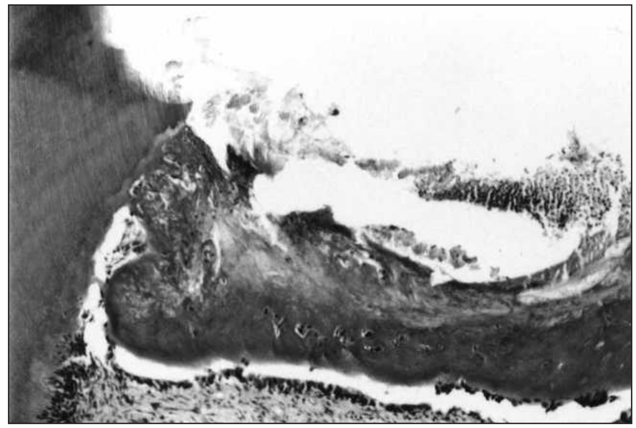


Figure 3. *Histologic picture of a tooth capped with Dycal at the 30th post-operative day. A relatively thick and complete dentin bridge has been formed. The dentin bridge has cellular inclusions and is entirely of the osteodentin type. Below the dentin bridge is a layer of odontoblast-like cells. The space between this layer and the dentin bridge is a sectioning artifact. The deep pulp looks normal, with no inflammatory cells visible. (H & E, x80, 2-47-7L).*

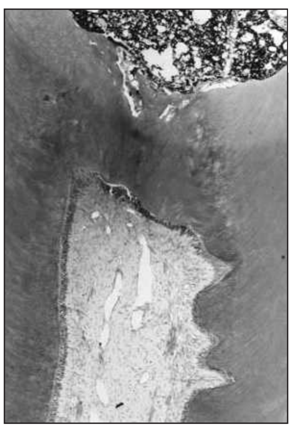


Figure 4. *Histologic picture of a tooth capped with Dycal at the 90th post-operative day. A thick dentin bridge composed mainly of tubular dentin is present adjacent to the capping material, and there is normal pulp morphology. This is an excellent example of pulpal healing and repair. The dilated blood vessels in the midpulp were probably caused by the perfusion fixation procedure. (H & E, x80, 1-32-4L).*

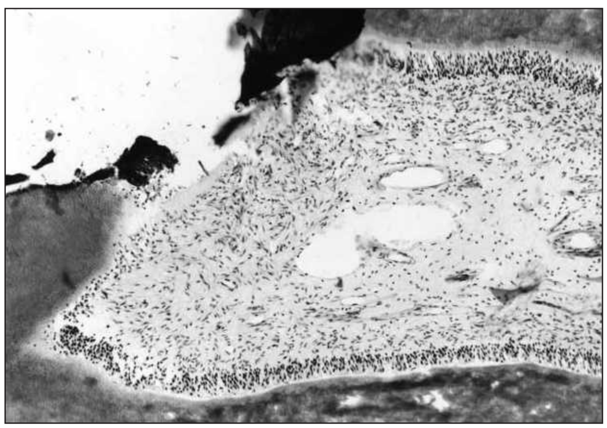


Figure 5. *Histologic picture of a tooth capped with Perme Bond F (Group 7) at the 3rd post-operative day. A thin necrotic zone is present below the resin (black material). There is mild tissue disorganization and a few inflammatory cells among the fibroblasts. Deep pulp appears normal. (H & E, x100, 5-34-19R).*

Figure 6. *Histologic picture of a tooth capped with One Step (Group 5) at the 30th post-operative day. There is initial dentin bridge formation at the periphery of the exposure. A layer of odontoblast-like cells that is continuous with the primary odontoblasts are at the surface and adjacent to the dentin bridge. There is also fibroblastic proliferation in the midpulp but very few inflammatory cells. (H & E, x 125, 2-41-13L).*

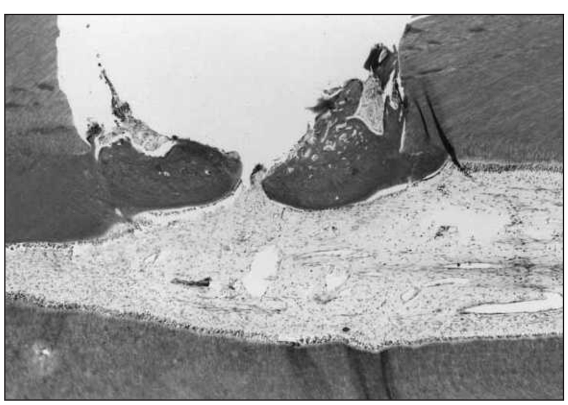


Figure 7. *Histologic picture of a tooth capped with Single Bond (Group 3) at the 90th post-operative day. An incomplete dentin bridge with a tunnel defect is visible. The bridge is partly osteodentin and partly tubular dentin and is continuous with the thick reactionary dentin to the left of the picture. The defect contains a few macrophages and pulp cells and could be attached to the vital pulp tissue on top of the dentin bridge. One or two layers of odontoblast-like cells is adjacent to the dentin bridge and is also connected to the primary odontoblasts at both ends of the exposure. (H & E, x60, 1-41-28L).*

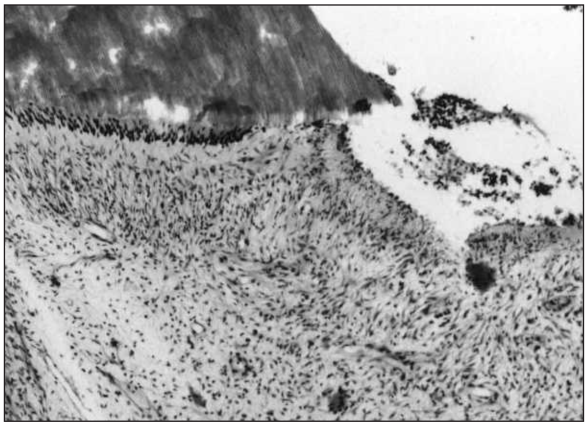


Figure 8. *Histologic picture of a tooth capped with Imperva Fluorobond (Group 4) at the 3rd post-operative day. There is mild soft tissue disorganization and moderate inflammatory cell infiltration (mostly mononuclear leukocytes and macrophages) scattered among the fibroblasts. Dentin chips at the surface and in the deep pulp appear as dark objects. A small resin globule at the surface is also present. (H & E, x80, 5-37-9R).*

Figure 9. *Histologic picture of a tooth capped with Prime&Bond NT (Group 6) at the 30th post-operative day. A collection of mononuclear inflammatory cells and macrophages at the surface is visible. They are clustered around objects that look like resin globules. No reactionary dentin nor reparative dentin formation is evident and there appears to be a reduction in the number of cells in the odontoblastic layer extending to areas distant from the exposure. (H & E, x60, 1-37-13L).*

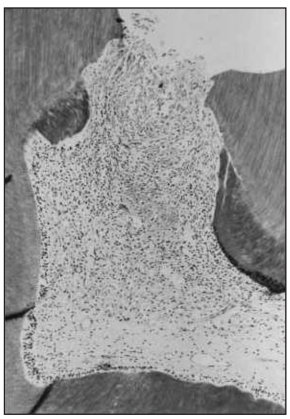


Figure 10. *Histologic picture of a tooth capped with AQ Bond (Group 2) at the 90th post-operative day. A severe inflammatory cell infiltrate composed of mononuclear leukocytes may be seen, as well as fibroblastic changes at the surface and in the midpulp. Reactionary dentin has formed at both sides of, but not immediately beside, the exposure site. This is probably due to the chemical toxicity of the adhesive resin. Also, there appears to be no attempt at reparative dentin formation or reorganization of the odontoblastic layer near the exposure. However, the deep pulp has a normal morphology. (H & E, x100, 5-15-19R).*

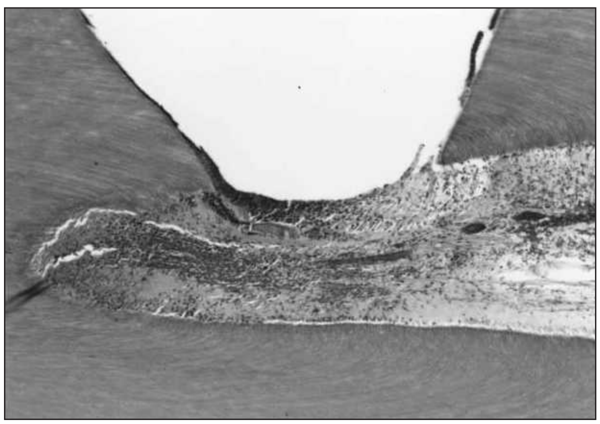


Figure 11. *A typical histologic picture of a tooth capped with Prime&Bond NT(Group 6) at the 3rd post-operative day. There are RBCs at the surface and in the mid-pulp reaching areas far from the exposure site. The severe tissue disorganization also extends to the opposite lingual wall. (H & E, x100, 1-12-10L).*

the groups showed reorganized odontoblastic layers and normal pulp morphology except Groups 2, 4 and 6, which had two or more teeth with severe disorganization and most of them also stained positively for bacteria.

Inflammatory Cell Infiltration

The Kruskal-Wallis Test for the inflammatory cell infiltration data after three days revealed a significant difference between groups (KW Chi^2 =19.66, p=0.0064). Post-hoc testing showed that Groups 4, 6, and 8 had significantly higher inflammatory cell infiltration than the control group. These groups had predominantly moderate or severe inflammation, while the other groups had mostly mild inflammation. Group 6 had one case with moderate inflammation and three necrotic pulps, all of which were negative for bacterial penetration.

After 30 days, Groups 2, 4, 5 and 6 had teeth with severe inflammation or necrotic pulps, but those of Group 4 were not associated with bacterial presence. Only one case of mild inflammatory cell infiltration was seen in Group 1, while Groups 3 and 7 had none or mild inflammation. The degree of inflammatory cell infiltration of the adhesive groups at this observation period was not significantly different from the control group.

The Kruskal-Wallis Test for the inflammatory cell infiltration data after 90 days revealed a significant difference between groups (KW Chi^2 =19.80, p=0.006). Post-hoc testing showed that Groups 2, 4 and 6 had significantly higher cell infiltration than the control group. They predominantly had moderate and severe/necrotic pulps except for a mild case each for Groups 2 and 6. Seven out of 13 specimens with moderate or severe/necrotic cases were associated with bacterial presence. The control group had only one case of mild inflammation, followed by Group 5, which had none or mild inflammation in all five specimens. Groups 3 and 7 had relatively good results with predominantly none and mild inflammatory cell infiltration, but each had a case with severe inflammation. Both cases were associated with the presence of bacteria.

Reparative Dentin Formation

The terms "reparative dentin" and "dentin bridge" will be used interchangeably; they both refer to the dentin matrix laid down by a new generation of odontoblast-like cells in response to a strong stimulus after the death of the original (primary) post-mitotic odontoblasts responsible for primary and physiologic secondary dentin deposition. This is differentiated from reactionary dentin, which is dentin matrix laid down by surviving post-mitotic odontoblast cells in response to a relatively mild stimulus (Smith & others, 1995).

After three days, no reparative dentin formation was observed in any of the groups.

After 30 days, only Group 1 was able to form complete dentin bridges (4 of 5 teeth). The Kruskal-Wallis Test for the dentin bridge formation data after 30 days revealed a significant difference between groups (KW Chi^2=20.26, p=0.005). Post-hoc testing showed that Groups 2, 3, 4 and 6 had significantly lower dentin bridge formation than the control group. Group 8 had the second highest number of dentin bridges formed (3). One tooth had initial reparative dentin formation and two cases had incompletely formed dentin bridges. The other adhesive groups had only one or two cases with initial reparative dentin formation. All the dentin bridges formed at this time were of the osteodentin type.

After 90 days, Group 1 had complete dentin bridges in all five cases. Two were of the osteodentin type and three were approximately 80% tubular dentin. The Kruskal-Wallis Test for the dentin bridge formation data after 90 days revealed a significant difference between Groups (KW Chi^2 =21.89, p=0.003). Post-hoc testing showed that Groups 2, 4 and 6, had significantly lower dentin bridge formation than the control group. Group 8 had three complete dentin bridges (100% tubular) and one incomplete dentin bridge (100% osteodentin). Group 5 had two incomplete and two complete dentin bridges, which were all tubular.

The formation of reparative dentin in most cases was initiated by the presence of dentin chips when they were located in the superficial pulp tissue. Dentin chips lodged deep in the pulp also acted as foci of reparative dentin formation and were not associated with appreciable numbers of inflammatory cells.

Bacterial Penetration

There was no case of positive bacterial staining after three days.

After 30 days, the adhesive groups had eight teeth (23%) with bacteria. Five were associated with severe inflammation or necrotic pulps, two with moderate inflammation and only one with mild inflammation. However, the Kruskal-Wallis test revealed no significant difference among the groups

After 90 days, the adhesive groups had 10 cases (29%) among them with bacteria and most were associated with moderate, severe inflammation or necrotic pulps. However, there was no significant difference among the groups.

Kendall correlation revealed a statistically significant correlation between inflammation and the presence of bacteria (Kendall Tau b=0.43, $p<.0001$).

The number of stained bacteria was generally few. In all the specimens with bacteria, no dentin bridge was formed except in one case of Group 8 at the 30-day observation period.

DISCUSSION

The histopathologic examination and subsequent statistical analyses of the data showed that the groups could be classified into those with acceptable results and those with unacceptable results. Acceptable results are those with predominantly none and mild responses and unacceptable results are those with moderate and severe responses (Mjör & Tronstad, 1972), The control group, Groups 3, 5, 7 and 8 could be classified as generally having acceptable results, while Groups 2, 4 and 6 mostly had unacceptable results. These results, which show significant differences in the pulpal responses to the different adhesive resins, reinforce the conclusion of others that the pulpal response is affected by the type of material and not just by the presence or absence of bacteria (Heys & others, 1981; Katoh, 1993; Katoh, 1997; Katoh & others, 1997b; Katoh & others, 1999; Sonoda & others, 2001).

The results of the control group were not significantly different from Groups 3, 5, 7 and 8, although some notable differences were observed. This prompted the authors to compare and separately discuss their performance as direct pulp capping materials.

The results showed that calcium hydroxide elicits none or mild inflammation shortly upon application and there is a faster resolution of the inflammation than in the other groups. It also showed that it induces the formation of reparative dentin earlier and deposition is at a faster rate, confirming the results of other studies (Ebihara & Katoh, 1996; Katoh & others, 1997b, Suzaki & Katoh, 1997; Jin & others, 2000). Proof of this is the higher incidence of reparative dentin

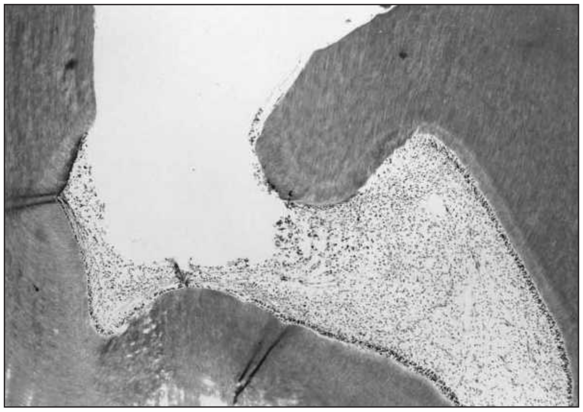


Figure 12. *Histologic picture of pulpal response associated with presence of bacteria. This is a specimen capped with Single Bond (Group 3) at the 90th post-operative day. There is no reactionary dentin or reparative dentin formation. The few stained bacteria were located at the buccal (right wall) wall of the preparation. The coronal pulp contains a mixture of polymorphonuclear cells, mononuclear leucocytes, and lymphocytes but the radicular pulp appears normal. (H & E, x60, 5-14-31L).*

Figure 13. *Histologic picture showing moderate inflammatory cell infiltration and complete dentin bridge formation. This is a specimen capped with One-up Bond F (Group 8 at the 90th post-operative day). The dentin bridge appears tubular and porous, and is associated with several layers of odontoblast-like cells. There is also thick reactionary dentin on both sides of the exposure. A dentin chip is seen covered with reparative dentin. The macrophages below the reorganized odontoblastic layer have engulfed particles that look like resin globules. (H & E, x100, 1-46-13L).*

formation after 30 days. There were already complete dentin bridges formed, supporting the findings of other studies that reparative dentin formation starts as early as the seventh post-operative day (Tarim & others, 1998; Cox & others, 1998). The incidence of reparative dentin formation in the control group after 90 days was not significantly higher than in Groups 3, 5, 7 and 8. However, there is an observable trend of higher incidence in calcium hydroxide capped teeth (100%) than in adhesive resin capped teeth (80%). This trend was observed even in studies that recommend the use of adhesive resin for direct pulp capping. One study's calcium hydroxide control group had 93% reparative dentin for the intermediate (21-35 days) and long-term (90-97 days) periods, while the adhesive groups had 87% for the same observation periods (Cox & others, 1998). This was almost the same as percentages for the control group and Clearfil Liner bond of 95% and 84%, respectively, which was reported by Akimoto & others (1998). Another study reported a lower incidence of 75% for calcium hydroxide capped teeth and 50% for Optibond system capped teeth (Tarim & others, 1998). Whatever the exact percentages, all these studies reported a higher incidence of reparative dentin formation in calcium hydroxide capped teeth than in resin-capped teeth.

These excellent results of calcium hydroxide as a direct pulp capping material could be attributed to its high pH which may: 1) act as a local buffer against the acidic reactions produced by the inflammatory process (Heithersay, 1975,); 2) initiate or favor mineralization because of the free hydroxyl ions (Tronstad & others, 1981); 3) activate alkaline phosphatase, which is postulated to play an important role in hard tissue formation (Guo & Messer, 1976) and 4) afford bactericidal properties as demonstrated by Fischer (1972).

The superior adhesion of the resin-modified glass ionomer cement placed on top of the calcium hydroxide capping material that prevented microleakage could also have contributed to the results of the control group.

The generally acceptable results of Groups 3, 5, 7 and 8 suggest that these adhesive resins are biocompatible with pulp tissue. These findings affirm the results of studies cited in the introduction, showing good outcome in resin-capped teeth when bacteria and microleakage are prevented. The initial reaction of Group 8 was unacceptable in all five specimens, but there seems to be progressive improvement with simultaneous dentin bridge formation over time. Only three teeth had moderate inflammatory cell infiltration at the 30-day observation period and two of these could be attributed to the presence of bacteria. At the 90-day observation period, the number of unacceptable results decreased further to two (one moderate and one necrotic pulp). It is very likely that the necrotic pulp was a result of extensive mechanical trauma due to the relatively large exposure size (1.12 mm). There was also a sign that excessive bur penetration reaching the opposing lingual wall had occurred. This specimen's pulp could have become necrotic early on because no reactionary dentin formation was observed. Although there was a persistence of chronic inflammation in these groups even after 90 days, it did not preclude the formation of dentin bridges. Among these four adhesives, only One Step (Group 5) had ever been investigated as a direct pulp-capping agent. It was also observed that One Step, along with the other adhesive resins tested, could elicit acceptable pulp responses (Cox & others, 1998).

Groups 2, 4 and 6 had significantly more inflammatory reaction and significantly less reparative dentin formation than the control group. These two findings would suggest that these adhesive systems and their composite resin systems may not contribute to pulp healing and repair as well as the other pulp capping materials for two reasons: first, these materials were not able to prevent microleakage in a number of specimens. This resulted in bacterial penetration in 10 teeth of these groups. The bacteria could have caused or aggravated the unacceptable results in these teeth. This hypothesis is based on an analysis of the entire data showing good correlation of bacterial presence and the severity of inflammatory cell infiltration that has also been observed in other studies (Bergenholtz & others, 1982; Fujitani, Inokoshi & Hosoda, 1992; Camps & others, 2000). It has been observed that bacteria, when present, were often associated with severe inflammation or necrotic pulps. Second, there is reason to believe that the chemical components of these adhesive resins may not be compatible with pulp tissue. Thirty specimens in these groups had unacceptable degrees of inflammatory cell infiltration, but only 10 were positive for bacteria, making us question the biocompatibility of these adhesive resins. The chemical biocompatibility of adhesive resins has also been questioned by other studies (Vojinovic, Nybörg & Brännström, 1973; Stanley, Going & Chauncey, 1975; Franquin & Brouillet, 1988; Qvist, Stoltze & Qvist, 1989; Tagami, Sugizaki & Hosoda, 1990; Pashley, 1992). Another possible reason for the adverse reactions in the absence of bacteria is microleakage, itself. Microleakage per se has been implicated in pulp irritation. It has been proposed that microleakage is associated with a pumping action due to thermal and mechanical stresses (Fusayama, 1980). This pumping action may possibly irritate the pulp through changes in pressure and by driving irritants of bacterial or other origin into the tubules (Fusayama, 1980).

It was observed that there were differences in the teeth with moderate or severe reactions that had bacteria and those that did not have them. The teeth with bacteria usually presented with abscess formation with mixed acute and chronic inflammatory cells or a dense infiltrate of chronic inflammatory cells that cover a large area. The majority of these teeth also had no dentin bridges and no or thin reactionary dentin (Figure 12). The observation that the presence of bacteria is often associated with a more severe pulp response agrees with the findings of Camps & others (2000). The teeth with no bacteria were often seen to have a collection of chronic inflammatory cells (mostly macrophages and lymphocytes) and increased fibrosis. There was also considerable reactionary dentin and sometimes dentin bridge formation (Figure 13).

The pulp responses to the adhesive groups did not appear related to the classification of the system (that is, single-bottle or self-etching primer). There is, however, some similarity among the groups that were biocompatible and those considered not biocompatible. The latter group contained UDMA and the former was Bis-GMA-based. It is hypothesized that UDMA, singly or in combination with the other resin components, could have produced the adverse tissue reactions. It has been found that resin components in dentin bonding systems may result in synergism, additivism and antagonism of individual cytotoxicities (Ratanasathien & others, 1995). The toxicity of these components was also ranked as follows: Bis-GMA>UDMA>TEGDMA>>> HEMA (least toxic). Although UDMA was found to be less toxic than Bis-GMA, the interaction with other resin components could have resulted in synergism or additivism and caused the adverse pulp responses in these groups.

The results of this study showed that when microleakage is prevented, some adhesive resin systems (Groups 3, 5, 7 and 8) and their accompanying composite system could elicit tissue responses comparable to calcium hydroxide. However, the prerequisite of eliminating microleakage is not easily achieved even with the latest bonding resins. This study observed that 17% of the specimens leaked and stained positive for bacteria. This figure is similar to that observed for Scotchbond Multi-purpose Plus of 15% (Pereira & others, 2000). A recent study that tested the biocompatibility of nine adhesive systems observed that 22% of the specimens had bacteria (Cox & others, 1998). Another study using a self-etching primer (Clearfil Liner Bond) also had bacteria in 22% of their specimens (Akimoto & others, 1998) while a fourth generation adhesive (Optibond) had only 9% (Tarim & others, 1998). Two direct capping studies in humans observed even higher values for leakage. Costa & others (2001) and do Nascimento & others (2000), using a self-etching primer (Clearfil Liner Bond 2), reported that 43% and 45% of their specimens, respectively, had varying degrees of bacterial penetration. The actual percentage of specimens with leakage in all these studies should be considered lower than the actual number because of reported limitations of staining bacteria in decalcified sections. They include, among others 1) the difficulty in staining gram-negative organisms (Cox & others, 1995); 2) loss of bacteria during tissue processing (Cox & others, 1995) and 3) changes in staining affinity produced by different decalcification agents (Wijnbergen & Van Mullem, 1987). Although the performance of adhesive resins has been improving from one adhesive generation to the next, these findings show that the ability to form a hermetic seal using adhesive resins is still not guaranteed. This has been considered "the major remaining shortcoming of modern adhesives" (Van Meerbeek & others, 1997). Considering this limitation of adhesive resins, the early formation and higher incidence of reparative dentin formation should be recognized as a distinct advantage of calcium hydroxide over adhesive resins as a direct-pulp capping material.

Some pulp biologists, however, have questioned the clinical importance of the reparative dentin formed adjacent to calcium hydroxide capping material because of the presence of tunnel defects. They argue that these structural imperfections render these dentin bridges incapable of providing a long-term barrier to bacterial infection (Cox & others, 1996b). This issue of tunnel defects in calcium hydroxide capped teeth has been clarified as not being caused by the capping material but due to the persistence of vascular channels, and their number would depend on the degree of trauma to the pulp tissue (Stanley & Pameijer, 1997). In addition, Stanley (1998) expounded on the value of these dentin bridges. He stated that however imperfect these dentin bridges are, they still provide some degree of pulp protection or secondary barrier to the pulp tissue that would allow it to produce more reparative dentin as the need arises. They are also considered essential for success because they provide the remaining pulp tissue something to attach to. Unattached pulp tissue, in cases without dentin bridge formation, would undergo degeneration, atrophy and shrinkage away from the dentin. It is also widely accepted that tissue healing and formation of a hard tissue barrier that completely covers the exposure site characterize a successful direct pulp capping procedure (Tziafas, 1997).

Studies on human teeth conducted in our department have shown good results with resin-capped teeth (Katoh, 1993; Katoh, 1997; Katoh, Kimura & Inaba, 1999). This makes the authors confident that these four adhesive resins (Single Bond, One Step, Perme Bond F, One-up Bond F) would also perform well in a clinical study. Pending the results of a clinical study on these materials, judgment that they can be used as direct pulp capping materials must be deferred. This clarification is necessary in light of a recent review on capping with dentin adhesives that concluded that results in animal teeth could not be directly extrapolated to human clinical conditions probably due to different healing capacities between species (Costa, Hebling & Hanks, 2000). The authors consider this study as a screening test to determine which adhesive resins would have the potential to perform well and, therefore, would be considered for inclusion in a clinical study.

CONCLUSIONS

Based on the results of this study, it is concluded that:

1. The response of monkey pulps to Single Bond, One Step, Perme Bond F and One-up Bond F is generally comparable to calcium hydroxide. However, calcium hydroxide could induce earlier and more consistent formation of reparative dentin, which should be considered an advantage over the adhesive resins.
2. AQ Bond, Imperva Fluorobond and Prime&Bond NT should not be considered for direct pulp capping until further studies could show contrary results.

Acknowledgement

The authors thank all the manufacturers of the adhesive resins and composite resin systems for generously providing the materials. They are also grateful to Macario F Reandelar, Jr, MD, Biostatistics Consultant, Department of Community and Family Medicine, Institute of Medicine, Far Eastern University-Nicanor Reyes Medical Foundation for his invaluable help with the statistical analysis.

Source of Funding

This study was supported by a grant-in-aid for Scientific Research (A)(1) from the Japan Society for the Promotion of Science (Project number: 12307045).

(Received 1 November 2001)

References

Akimoto N, Momoi Y, Kohno A, Suzuki S, Otsuki M, Suzuki S & Cox CF (1998) Biocompatibility of Clearfil Liner Bond 2 and Clearfil AP-X system on non-exposed and exposed primate teeth *Quintessence International* **29(3)** 177-188.

Alacam A, Tulunoglu O, Oygur T & Bilici S (2000) Effects of topical Catalase application on dental pulp tissue: A histopathological evaluation *Journal of Dentistry* **28(5)** 333-339.

Baume LJ & Holz J (1981) Long-term clinical assessment of direct pulp capping *International Dental Journal* **31(4)** 251-260.

Bergenholtz G, Cox CF, Loesche WJ & Syed SA (1982) Bacterial leakage around dental restorations: Its effect on the dental pulp *Journal of Oral Pathology* **11(6)** 439-450.

Brännström M & Nyborg H (1972) Pulpal reaction to composite resin restorations *Journal of Prosthetic Dentistry* **27(2)** 181-189.

Camps J, Déjou J, Rémusat M & About I (2000) Factors influencing pulpal response to cavity restorations *Dental Materials* **16(6)** 432-440.

Costa CA (2001) Response of human dental pulp to dentin adhesive systems *The International Conference on Dentin/Pulp Complex* **Program and Abstracts** S-5-4.

Costa CA, Hebling J & Hanks CT (2000) Current status of pulp capping with dentin adhesive systems: A review *Dental Materials* **16(3)** 188-197.

Costa CA, Lopes do Nascimento AB, Texiera HM & Fontana UF (2001) Response of human pulps capped with a self-etching adhesive system *Dental Materials* **17(3)** 230-240.

Cox CF & Suzuki S (1994) Re-evaluating pulp protection: $Ca(OH)_2$ liners versus cohesive hybridization *Journal of the American Dental Association* **125(7)** 823-831.

Cox CF, Bergenholtz G, Heys DR, Syed SA, Fitzgerald M & Heys RJ (1985) Pulp capping of dental pulp mechanically exposed to oral microflora: A 1-2 year observation of wound healing in the monkey *Journal of Oral Pathology* **14(2)** 156-168.

Cox CF, Hafez AA, Akimoto N, Otsuki M, Suzuki S & Tarim B (1998) Biocompatibility of primer, adhesive and resin composite systems on non-exposed and exposed pulps of non-human primate teeth *American Journal of Dentistry* **11(Spec No)** S55-63.

Cox CF, Keall CL, Keall HJ, Ostro E & Bergenholtz G (1987) Biocompatibility of surface-sealed dental materials against exposed pulps *Journal of Prosthetic Dentistry* **57(1)** 1-8.

Cox CF, Sübay RK, Suzuki S, Suzuki SH & Ostro E (1996a) Biocompatibility of various dental materials: Pulp healing with a surface seal *International Journal of Periodontics and Restorative Dentistry* **16(3)** 240-251.

Cox CF, Sübay RK, Ostro E, Suzuki S & Suzuki SH (1996b) Tunnel defects in dentin bridges: Their formation following direct pulp capping *Operative Dentistry* **21(1)** 4-11.

Cox CF, Suzuki S, Suzuki SH & Cox LK II (1995) Histological evaluation of direct pulp capping with various adhesive systems *Proceedings of the International Conference on Dentin/Pulp Complex: Quintessence International* **(Special Issue)** p 209-216.

do Nascimento AB, Fontana UF & Costa CA (1998) Histologic evaluation of human pulp in direct contact with different materials *Journal of Dental Research* **77(Special Issue B)** Abstract #466 p 690.

do Nascimento AB, Fontana UF, Texiera HM & Costa CA (2000) Biocompatibilty of a resin-modified glass-ionomer cement applied as pulp capping in human teeth *American Journal of Dentistry* **13(1)** 28-34.

Ebihara T & Katoh Y (1996) Histopathological study on development of adhesive resinous materials containing calcium hydroxide as direct pulp capping agent *The Japanese Journal of Conservative Dentistry* **39(6)** 214-233.

Fischer FJ (1972) The effect of calcium hydroxide/water paste on micro-organisms in carious dentine *British Dental Journal* **133(1)** 19-21.

Ford TR, Torabinejad M, Abedi HR, Bakland LK & Kariyawasam SP (1996) Using mineral trioxide aggregate as a pulp-capping material *Journal of the American Dental Association* **127(10)** 1491-1494.

Franquin JC & Brouillet JL (1988) Biocompatibility of an enamel and dentin adhesive under different conditions of application *Quintessence International* **19(11)** 813-826.

Fujitani M, Inokoshi S & Hosoda H (1992) Effect of acid etching on the dental pulp in adhesive composite restorations *International Dental Journal* **42(1)** 3-11.

Fusayama T (1980) New concepts in operative dentistry, Chicago,IL Quintessence Publishing Co p 61-156.

Gao Y, Fang YR, Suwa F, Yoshida S, Yang L & Tanaka A (1995) Induction of reparative dentin formation in dogs by bovine bone morphogenetic protein bound to ceramic dentin *Journal of the Osaka Dental University* **29(1)** 29-38.

Goracci G, Mori G & Bazzucchi M (1995) Marginal seal and biocompatibility of a fourth-generation bonding agent *Dental Materials* **11(6)** 343-347.

Guo MK & Messer HH (1976) Properties of Ca^{2+} Mg^{2+} activated adenosine triphosphate from rat incisor pulp *Archives of Oral Biology* **21(11)** 637-640.

Gwinnett AJ & Tay FR (1997) Early and intermediate time response of the dental pulp to an acid etch technique *in vivo American Journal of Dentistry* **10(Spec no)** S35-S44.

Hayashi Y, Imai M, Yanagiguchi K, Viloria IL & Ikeda T (1999) Hydroxyapatite applied as direct pulp capping medicine substitutes for osteodentin *Journal of Endodontics* **25(4)** 225-229.

Hebling J, Giro EM & Costa CA (1999) Biocompatibility of an adhesive system applied to exposed human dental pulp *Journal of Endodontics* **25(10)** 676-682.

Heithersay GS (1975) Calcium hydroxide in the treatment of pulpless teeth with associated pathology *Journal of the British Endodontic Society* **8(2)** 74-93.

Heitmann T & Unterbrink G (1995) Direct pulp capping with a dentinal adhesive system: A pilot study *Quintessence International* **26(11)** 765-770.

Hermann BW (1920) [Calciumhydroxyd als mittel zum behandeln und fullen von wurzelkanalen] *(Dissertation)* University of Wurzburg, Germany.

Heys DR, Cox CF, Heys RJ & Avery AK (1981) Histological considerations of direct pulp capping agents *Journal of Dental Research* **60(7)** 1371-1379.

Higashi T & Okamoto H (1996) Influence of particle size of calcium phosphate ceramics as a capping agent on the formation of a hard tissue barrier in amputated dental pulp *Journal of Endodontics* **22(6)** 281-283.

Inoue T & Shimono M (1992) Repair dentinogenesis following transplantation into normal and germ-free animals *Proceedings of the Finnish Dental Society* **88(Supplement 1)** 183-194.

Jin C, Shinkai K & Katoh Y (2000) New developments in histopathological studies on adhesive resinous materials having a calcification promoting function as direct capping agent-the effect of $Ca(OH)_2$ on direct capping with self-etching primer and the wound healing process over time *The Japanese Journal of Conservative Dentistry* **43(1)** 85-108.

Katoh M, Kidokoro S & Kurosu K (1978) A study on the amputation of pulp using sodium hypochloride (NaOCl) Japanese *Journal of Pediatric Dentistry* **(16)** 107-116.

Katoh Y (1993) Clinico-pathological study on pulp irritation of adhesive resinous material, Report 1- Histopathological change of the pulp tissue in direct capping *Journal of the Japan Society for Adhesive Dentistry* **11(4)** 199-211.

Katoh Y (1997) Microscopic observation of the wound healing process of pulp directly capped with adhesive resins *Journal of the Japan Society for Adhesive Dentistry* **15(3)** 199-211.

Katoh Y, Kimura T & Inaba T (1997a) Long-term clinical prognosis of pulp tissue direct capped with adhesive resins *Journal of Dental Research* **77(Special Issue)** Abstract #36 p 636.

Katoh Y, Yamaguchi R, Shinkai K, Hasegawa K, Kimura T, Ebihara T, Suzaki T, Ohara A, Kitamura Y, Tanaka N, & Jin C (1997b) Clinicopathological study on pulp irritation of adhesive resinous materials-Report 3: Direct capping effects on exposed pulp of Macaca fascicularis *The Japanese Journal of Conservative Dentistry* **40(1)** 163-176.

Katoh Y, Kimura T & Inaba T (1999) Clinicopathological study on pulp irritation of adhesive resinous materials-Report 4: Long-term clinical prognosis of pulp tissue directly capped with resinous materials *The Japanese Journal of Conservative Dentistry* **42(5)** 989-995.

Katoh Y (2001) Hybridized capping effect of two step bonding system and $Ca(OH)_2$ to exposed *The International Conference on Dentin/Pulp Complex* **Program and Abstracts** S-5-5.

Kidd EA (1976) Microleakage: A review *Journal of Dentistry* **4(5)** 199-206.

Kitasako Y, Inokoshi S & Tagami J (1999) Effects of direct resin pulp capping techniques on short-term response of mechanically exposed pulps *Journal of Dentistry* **27(4)** 257-263.

Kitasako Y, Inokoshi S, Fujitani M, Otsuki M & Tagami J (1998) Short-term reaction of exposed monkey pulp beneath adhesive resins *Operative Dentistry* **23(6)** 308-317.

Kitasako Y, Shibata S, Pereira PN & Tagami J (2000) Short –term dentin bridging of mechanically exposed pulps capped with adhesive resin systems *Operative Dentistry* **25(3)** 155-162.

Lim KC & Kirk EE (1987) Direct pulp capping: A review *Endodontics & Dental Traumatology* **3(5)** 213-219.

McWalter GM, El-Kafrawy AH & Mitchell DF (1973) Pulp capping in monkeys with a calcium hydroxide compound, an antibiotic, and a polycarboxylate cement *Oral Surgery, Oral Medicine, Oral Pathology* **36(1)** 90-100.

Mjör IA & Tronstad L (1972) Experimentally induced pulpitis *Oral Surgery, Oral Medicine, Oral Pathology* **34(1)** 102-108.

Olmez A, Oztas N, Basak F & Sabuncuoglu B (1998) A histopathologic study of direct pulp-capping with adhesive resins *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics* **86(1)** 98-103.

Onoe N, Inokoshi S, Yamada T (1996) Histopathological evaluation of adhesive resins for direct pulp capping *Proceedings of the International Conference on Dentin/Pulp Complex: Quintessence International* **(Special Issue)** 221-226.

Otsuki M, Tagami J, Kanca J III, Akimoto N, Suzuki SH, Suzuki S & Cox CF (1997) Histological evaluation of two BISCO adhesive systems on exposed pulps *Journal of Dental Research* **76(Special Issue**) Abstract #520 p 251.

Pameijer CH & Stanley HR (1998) The disastrous effects of the "total etch" technique in vital pulp capping in primates *American Journal of Dentistry* **11(Spec No)** S45-S54.

Pashley DH (1992) The effects of acid etching on the pulpodentin complex *Operative Dentistry* **17(6)** 229-242.

Pereira JC, Segala AD & Costa CA (2000) Human pulp response to direct pulp capping with an adhesive system *American Journal of Dentistry* **13(3)** 139-147.

Qvist V, Stoltze K & Qvist J (1989) Human pulp reactions to resin restorations performed with different acid-etch restorative procedures *Acta Odontologica Scandinavia* **47(5)** 253-263.

Ratanasathien S, Wataha JC, Hanks CT & Dennison JB (1995) Cytotoxic interactive effects of dentin bonding components on mouse fibroblasts *Journal of Dental Research* **74(9)** 1602-1606.

Sasaki T & Kawamata-Kido H (1995) Providing an environment for reparative dentin induction in amputated rat molar pulp by high molecular-weight hyaluronic acid *Archives of Oral Biology* **40(3)** 209-219.

Shinkai K, Tanaka N, Kitamura Y, Takagi M, Suzuki S & Katoh Y (1997) Studies on new fluoride containing light-activated bonding resin. Part 3: Pulpal response in Macaca fascicularis *The Japanese Journal of Conservative Dentistry* **41(4)** 708-718.

Smith AJ, Cassidy N, Perry H, Begue-Kirn C, Ruch JV & Lesot H (1995) Reactionary dentinogenesis *International Journal of Developmental Biology* **39(1)** 273-280.

Sonoda H, Inokoshi S, Otsuki M & Tagami J (2001) Pulp tissue reaction to four dental cements *Operative Dentistry* **26(2)** 201-207.

Stanley HR & Pameijer CH (1997) Dentistry's friend: Calcium hydroxide *Operative Dentistry* **22(1)** 1-3.

Stanley HR (1998) Criteria for standardizing and increasing credibility of direct pulp capping studies *American Journal of Dentistry* **11(Spec No)** S17-34.

Stanley HR, Going RE & Chauncey HH (1975) Human pulp response to acid pretreatment of dentin and to composite restoration *Journal of the American Dental Association* **91(4)** 817-825.

Suzaki T & Katoh Y (1997) Histopathological study on 4-META/MMA-TBB resin containing calcium hydroxide as a direct pulp capping agent *The Japanese Journal of Conservative Dentistry* **40(1)** 49-77.

Tagami J, Sugizaki J & Hosoda H (1990) Effect of various pretreatments for dentin bonding on dentin permeability *Shika Zairyo Kikai* 9(2) Abstract 240-246.

Tanaka N & Katoh Y (2001) Histopathological study on pulpal response restored with an adhesive composite resin system after cutting by Er: YAG laser in Macaca fascicularis *The Japanese Journal of Conservative Dentistry* **44(2)** 214-233.

Tarim B, Hafez AA, Suzuki SH, Suzuki S & Cox CF (1998) Biocompatibility of Optibond and XR-Bond adhesive systems in non-human primate teeth *International Journal of Periodontics and Restorative Dentistry* **18(1)** 86-99.

Thomas GP, Boyd JB, Soni NN & Palmer JE (1995) Histologic study of pulp capping using chlorhexidine in dogs *National Dental Association Journal* **46(1)** 17-20.

Tronstad L, Andreasen JO, Hasselgren G, Kristerson L & Riis I (1981) pH changes in dental tissues after root canal filling with calcium hydroxide *Journal of Endodontics* **7(1)** 17-21.

Tsuneda Y, Hayakawa T, Yamamoto H, Ikemi T & Nemoto K (1995) A histopathological study of direct pulp capping with adhesive resins *Operative Dentistry* **20(6)** 223-229.

Tziafas D (1997) Reparative dentinogenesis: A monograph on the dentinogenic potential of dental pulp, Thessaloniki, University Studio Press p 41-55.

Van Meerbeek B, Perdigão J, Lambrechts P & Vanherle G (1997) The clinical performance of adhesives *Journal of Dentistry* **26(1)** 1-20.

Vojinovic O, Nybörg H & Brännström M (1973) Acid treatment of cavities under resin fillings: Bacterial growth in dentinal tubules and pulpal reactions *Journal of Dental Research* **52(6)** 1189-1193.

White KC, Cox CF, Kanka J III, Dixon DL, Farmer JB & Snuggs HM (1994) Pulpal response to adhesive resin systems applied to acid-etched vital dentin: Damp versus dry primer application *Quintessence International* **25(4)** 259-268.

Wijnbergen M & Van Mullem PJ (1987) Effect of histological decalcifying agents on number and stainability of gram-positive bacteria *Journal of Dental Research* **66(5)** 1029-1031.

Yoshiba K, Yoshiba N & Iwaku M (1995) Effects of antibacterial capping agents on dental pulps of monkeys mechanically exposed to oral microflora *Journal of Endodontics* **21(1)** 16-20.

Yoshimine Y & Maeda K (1995) Histologic evaluation of tetracalcium phosphate-based cement as a direct pulp-capping agent *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics* **79(3)** 351-358.

©*Operative Dentistry, 2002,* **27,** 343-348

Effects of Pre-Soaked Retraction Cords on the Microcirculation of the Human Gingival Margin

A Fazekas • F Csempesz • Zs Csabai • J Vág

Clinical Relevance

Vasoconstriction may be required for adequate control of sulcular seepage and/or hemorrhage, and is most probably provided by epinephrine-impregnated retraction cord. Laser Doppler flowmetry could be a practical aid in choosing a topically effective dose of epinephrine.

SUMMARY

In the direct treatment of cervical lesions and to improve the impression-making procedure prior to fabricating indirect restorations, exposure of the gingival sulcus and control of hemorrhage or gingival fluid seepage are a prerequisite. For gingival displacement, cords impregnated with medicaments are widely used. In this investigation, the authors first studied in vitro **the time course of fluid absorption by retraction cords immersed in test solutions. Thereafter, in a clinical trial, they examined the microcirculatory responses of the gingival margin after subgingival insertion and removal of retraction cords presoaked in solutions containing saline, $AlCl_3$, $Fe_2(SO_4)_3$ or epinephrine. Blood flow was recorded using laser Doppler technique. Blood perfusion fell markedly upon inserting the retraction cord, and this response was invariably present with all the compounds tested. After five-minutes, the decrease became less apparent with cords that were impregnated with physiological saline, $AlCl_3$ or $Fe_2(SO_4)_3$. Removing the cord elicited a prompt, marked and sustained increase in gingival microcirculation. However, removal of the cord impregnated with 0.1% epinephrine failed to reverse the decreased perfusion, and blood flow to the gingival margin remained low over an additional 20-minute observation. The results of this study indicate that with the exception of epinephrine, all retraction substances tested produced gingival hyperemia for operative procedures. Only epinephrine exhibited sustained vasoconstrictor response. It is anticipated that using laser Doppler flowmetry may be a suitable technique to evaluate the appropriate concentration of epinephrine that would elicit topical vasoconstriction.**

*Arpád Fazekas, DMD, PhD, DSc, professor and head, Semmelweis University Budapest, Department of Conservative Dentistry

F Csempesz, DMD, PhD, student, Semmelweis University Budapest

Zs Csabai, assistant professor, Semmelweis University Budapest

J Vág, assistant professor, Semmelweis University Budapest

*Reprint request: Mikszath tér 5. 1088 Hungary; e-mail: fazekas@konfog.sote. hu

INTRODUCTION

Gingival retraction techniques are commonly used to ensure adequate moisture control for Class V direct fillings. Exposure of the gingival sulcus helps to prevent abrasion of the marginal gingiva during cavity preparation, allows inspection of the gingival cavosurface margin and also helps to improve the impression procedure prior to fabricating indirect restorations.

The efficacy and actions on the sulcular epithelium of the various mechanical, chemical and surgical gingival retraction techniques and their combinations have been widely studied (Harrison, 1961; Nemetz, 1974; de Gennaro & others, 1982; Buchanan & Thayer, 1982; Nemetz, Donovan & Landesman, 1984; Donovan, Gandara & Nemetz, 1985). These studies, however, have failed to provide data on alterations in the microcirculation of the gingival margin during and after the gingival deflection procedure. Namely, synthesis of the macromolecules in the connective tissue ensures deformability of the free gingival margin, formation of the crevicular transudate and the incidence of periprocedural hemorrhage, all of which are primarily determined by tissue perfusion of the gingival margin and the actual state of the periodontal vessels.

This study was designed to investigate the effects of retraction cords, soaked in solutions of various substances, on the microcirculation of the gingival margin. This was done using laser Doppler technique on clinical patients. It was reasonable to suppose that perfusion responses in the gingival margin to sulcus exposure also depends on the amount of treatment solution absorbed per unit weight of cord. For purposes of standardization, the authors first studied the time course of fluid absorption by the cords under *in vitro* conditions. They presumed that having this data available would help when choosing the optimum retraction technique (cord, medicaments and more). The results may also help to avoid the potential irreversible soft or hard tissue damage of the periodontium that can occur during the impression procedure. Such damage may lead to gingival recession and makes estimating the ultimate level of gingival margin unpredictable. Fazekas & others (2000) presented a part of this study in a preliminary report in Hungarian.

METHODS AND MATERIALS

In Vitro Study of Fluid Absorption by Retraction Cords

Plain braided cord (#00, ULTRAPAC; Ultradent Products, Inc, South Jordan, UT 84095, USA) cut to identical lengths (35 mm each) was used as the retraction material. Each piece of cord was precisely weighed prior to soaking by using an electronic analytical balance (Mettler AE-200; Mettler-Toledo AG, Greifensee, Switzerland). The solutions tested were: epinephrine (0.1% w/v Tonogen, Richter Gedeon, Hungary), $AlCl_3$ (25% w/v), $Fe_2(SO_4)_3$ (15.5% w/v Ultradent Products, Inc), and saline as a control. Substances were tested using 25 pieces of cord in each group of medicaments. Time course study included gravimetric measurements of the cords at 2 seconds, 1, 5 and 60 minutes and at 24 hours (n=5 in each subgroup 1-5) of soaking in the impregnation solution. The amount of fluid absorbed by the cord was calculated as post-impregnation weight minus pre-impregnation weight and it was expressed as mg/mg cord. Data of the time course study were plotted in a linear coordinate system and the best-fit line was constructed (saturation function). The maximum amount of fluid absorbed by the cord with each test solution was calculated using the Michaelis-Menten equation. Accordingly, the reciprocal of time was plotted against the reciprocal of milligrams of fluid absorbed. The intercept of the best-fit line with the y-axis that was obtained gives the reciprocal of the saturation. The saturation time was calculated using the original plot.

Effect of Retraction Procedure on the Microcirculation of the Gingival Margin

Clinical studies were performed on healthy, non-smoking patients with good oral health (n=33; 18 males, 15 females, age 18-30 years). The presence or absence of inflammation in the gingival margin was checked by means of probing assessments according to the principles of the Gingival Index (Löe, 1967), Plaque Index (Silness & Löe, 1964) and gingival Sulcus Bleeding Index (Mühlemann & Son, 1971). Only patients with clinically healthy gingiva and no history of high blood pressure or regular use of medication were included. The retraction cord was saturated with the test solution and placed labially in the gingival sulcus along the distance from the mesial to distal papilla at one of the upper central incisors. To avoid even minimal inconvenience for the patients, data collection was maximized to 30 minutes and each subject participated only once in the study.

Recording Protocol

Blood flow of the gingival margin was measured by laser Doppler flowmetry (Oxford Optronix Ltd, Oxford, OX4 4GA, UK) 780 nm. The instrument and reproducibility of the technique have been described in detail elsewhere (Csempesz & others, 2000; Kerémi & others, 2000). In brief, a straight laser Doppler probe (diameter: 0.9 mm) was attached to the flowmeter and directed 1 mm apical to the gingival margin at right angles without touching the gingiva. The probe was positioned using a manipulator and fixed by an individually processed bite block made of silicon impression material. The laser Doppler flowmeter was connected to a computer that stored the data. Values are expressed in Blood Perfusion Units (BPU).

Blood flow readings were taken in a room with steady ambient temperature under calm conditions. During the study each patient was comfortably positioned in the recumbent position in a dental chair. The individual's teeth held the bite block, fixing the gingival probe. A retractor held the lips back. Care was taken to avoid strain of the mucosal tissue adjacent to the recording site. Recording perfusion of the gingival margin began after a control period of approximately five minutes. Control values were obtained after averaging the readings recorded in the last two minutes of the control period. Thereafter, the retraction cord saturated with the medicament was placed in the gingival sulcus without interrupting the recording of flow or without removing or touching the probe during this procedure. Then, after an additional five minutes of recording time, the retraction cord was removed. The recording of gingival perfusion was then continued for an additional 20 minutes. Each subject was exposed to only one test substance. The compounds tested were physiological saline (n=7), 0.1% epinephrine (n=9), 25% $AlCl_3$ (n=9) and 15.5% $Fe_2(SO_4)_3$ (n=8). All who were involved received a full explanation of the procedures and signed an informed consent. The study was in accordance with the Helsinki Declaration of 1975 and 1983.

Table 1: *Maximum Amounts of Fluid Absorbed by the Retraction Cord and Saturation Times*

Solution of Medicament	Fluid Absorbed (mg/1mg cord)	Saturation Time (seconds)
Physiological saline	4.4	360
Epinephrine (0.1% w/v)	3.6	229
$AlCl_3$ (25% w/v)	5.0	543
$Fe_2(SO_4)_3$ (15.5% w/v)	6.0	579

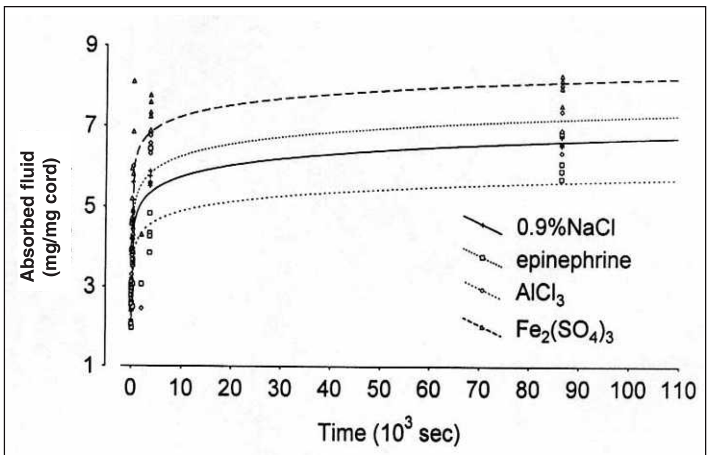


Figure 1. *Time course of absorption of various medicament solutions by the retraction cord. Time course of the dynamics is described as a logarithmic function: + 0.9% NaCl (y = 1.99 + 0.94 lgx); ❑ Epinephrine (y = 1.70 + 0.78 lgx); ◊ $AlCl_3$ (y = 2.04+1.06 lgx); Δ $Fe_2(SO_4)_3$ (y = 3.39+0.96 lgx).*

Statistical Analysis

Time related changes in blood flow of the gingival margin were statistically evaluated by analysis of variance followed by the Newman-Keuls test for post-hoc analysis. Data are means ± SEM. A $p<0.05$ was used as the level of significance.

RESULTS

The amount of fluid absorption by the cord used was markedly dependent on the time of immersion. The dynamics of fluid absorption exhibited a logarithmic relationship in a linear plot (Figure 1). The equations of the best-fit lines for the compounds tested were physiological saline: y=1.99+0.94 lgx (r=0.92, $p<0.001$); epinephrine: y=1.70+0.78 lgx (r=0.87, $p<0.001$); $AlCl_3$: y=2.04+1.06 lgx (r=0.95, $p<0.001$); $Fe_2(SO_4)_3$: y=3.39+0.96 lgx (r=0.90, $p<0.001$). Saturation levels calculated on the basis of Michaelis-Menten kinetics and saturation times are presented in Table 1.

According to the saturation times obtained, pieces of retraction cord were immersed in physiological saline, epinephrine solution, $AlCl_3$ and $Fe_2(SO_4)_3$ for 6, 4, 9 and 10 minutes, respectively, prior to application. Representative tracings of blood flow of the gingival margin during the periods after subgingival insertion and removal of the retraction cord are presented in Figures 2 and 3. Figure 4 illustrates overall data. One minute after inserting the retraction cord, a marked decrease in perfusion occurred compared to the baseline value with all substances tested (physiological saline: from 417±66 BPU to 208±31; $p<0.001$; $AlCl_3$: from 364±22 BPU to 199±2; $p<0.05$; $Fe_2(SO_4)_3$: from 369±66 BPU to 227±37; $p<0.05$; epinephrine: from 467±36 BPU to

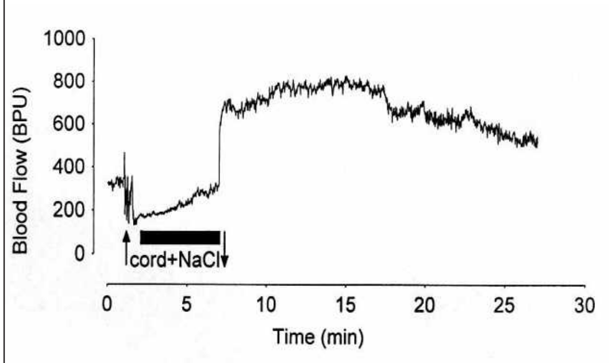


Figure 2. *Microcirculatory responses in the gingival margin after subgingival insertion (↑) and removal (↓) of physiological saline impregnated retraction cord. The period when retraction cord was in the gingival sulcus is indicated by the horizontal bar (cord + NaCl).*

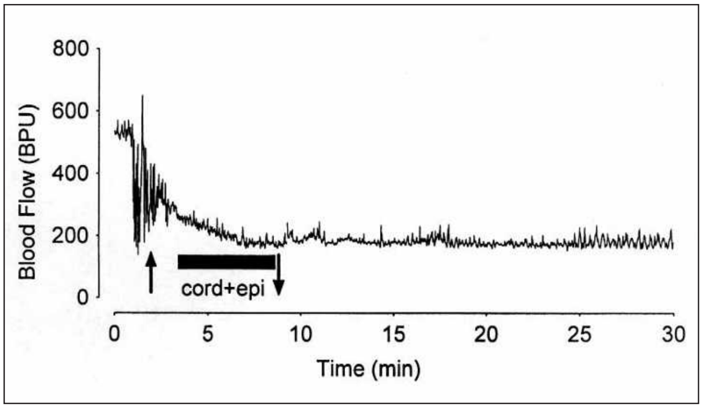


Figure 3. *Microcirculatory responses in the gingival margin after subgingival insertion (↑) and removal (↓) of epinephrine impregnated retraction cord. The period when retraction cord was in the gingival sulcus is indicated by the horizontal bar (cord + epi).*

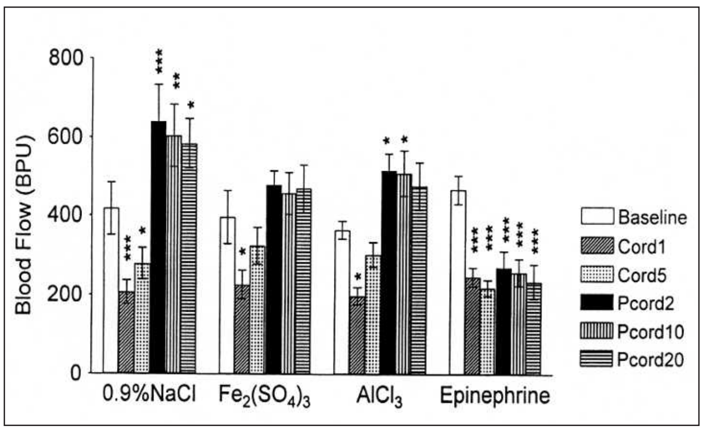


Figure 4. *Microcirculatory responses in the gingival margin in the control period (baseline), immediately after subgingival insertion of the retraction cords soaked in various medicaments (Cord 1), at five minute post-insertion (Cord 5), and 2 (Pcord 2), 10 (Pcord 10) and 20 (Pcord 20) minutes after removal. Data represent means + SEM. Comparisons were made using the appropriate controls.*p<0.05; **p<0.01; ***p<0.001.*

248±24; $p<0.001$). The degree of decrease in gingival perfusion was practically the same with each of the various compounds. The test substances can be divided into two groups based on the blood flow responses observed in the gingival margin that occurred later on. During the period of sulcus exposure by *in situ* retraction cords (five minutes) soaked in physiological saline $AlCl_3$ or $Fe_2(SO_4)_3$, the reduced blood flow tended to rise slowly (Figure 2). The slopes characterizing this trend were physiological saline: 17.4±4.4; $p<0.05$; $AlCl_3$: 24.6±4.7; $p<0.01$; $Fe_2(SO_4)_3$: 24.6±5.7; $p<0.05$. In cases of $AlCl_3$ and $Fe_2(SO_4)_3$ administration, readings recorded immediately prior to removing the cord did not appreciably differ from baseline values. Upon removing the retraction cord, there was a prompt increase in perfusion with all materials except epinephrine. In patients treated with physiological saline or $AlCl_3$, the increase in blood flow was significant as compared to the control two minutes after removing the cord (640±93 BPU; $p<0.001$ and 516±44 BPU; $p<0.05$). The trend of blood flow elevation could be noticed in the subjects with $Fe_2(SO_4)_3$ treatment. Thus, the hyperemic response of the gingival tissue observed after cord removal followed a nearly uniform pattern in cases of saline, $AlCl_3$ or $Fe_2(SO_4)_3$. The increment of blood flow was sustained; 10 or 20 minutes after cord removal it still prevailed. In the epinephrine group, the decrement in gingival perfusion registered after inserting the retraction cord remained practically unaltered, and this response was also sustained (two minutes after cord removal: 272± 41 BPU; $p<0.01$ vs control period). Gingival perfusion remained lower 10 minutes (259±34; $p<0.001$ vs control period), and 20 minutes (236±44; $p<0.001$ vs control period) after cord removal (Figure 3).

DISCUSSION

The protocol of this clinical trial was designed to contribute to improving clinical practice. To ensure fluid uptake, the cord was soaked in a solution-containing medicament. The amount of retraction fluid absorbed by the cord was standardized by determining the time required for saturation.

The cord (#00) employed in this study, owing to its non-shredding property, constant shape and absorbent capacity, seems to be well suited to expose the gingival sulcus and improve access and visibility. Since the air-trapping capacity of the braided cord is rather high, it may hinder fluid absorption during the impregnation process. To minimize this effect, the authors tried to press out the trapped air inclusions from the "core" of the cord by drawing it between the tightly closed thumb and index finger of the examiner while immersing the cord in the impregnation solution. Results of their fluid absorption studies revealed that the amount of absorbed fluid primarily depends on the time of soaking in the impregnation solution, while the chemical or physical properties of the medicaments exert only slight effects on it. To avoid the unwanted effects due to long-term storage of the cords in impregnation fluid, the authors recommend that cords of proper length should be soaked in the medicament solution (chosen from those tested in this study) uniformly for about 10 minutes. A shorter incubation time generally does not ensure even wetting of the cord, whereas long-term storage results only in a negligible increase in the amount of fluid absorbed.

Exposing the subgingival margin of a preparation prior to taking an impression for indirect restorations may be one of the most critical procedures for the dentist to perform. This procedure is further complicated by physiological variations in sulcal depth, distensibility of the gingival tissues, degree of gingival inflammation, level of marginal placement and tissue laceration during preparation (Nemetz & others, 1984). Either astringents or vasoconstrictors are used for gingival retraction. Astringents are locally acting drugs that precipitate proteins but have minimal penetrability such that only the surface of cells is affected. Their actions are, however, known to vary depending on chemical properties and concentrations. Employed in high concentrations, they exert hemostatic action, owing to their ability to coagulate the injured superficial cell layer. The vasoconstrictor agents belonging to the other group are also employed for hemostatic purposes. The medicaments applied in higher doses may enter the systemic circulation and may also elicit remote cardiovascular responses (Pelzner & others, 1978; Woycheshinn, 1964; Donovan & others, 1985). In this study, the amount of epinephrine loaded in the sulcus can be assessed on the basis of saturation level and weight of the cord. Thus, the assessed dose of epinephrine per cord (length: 7 mm, diameter: #00) should be about 2 µg.

These observations suggest that the mechanical effect of cord exerted on the free gingival margin was responsible for the prompt decrease in blood perfusion. This is supported by the fact that in this period no differences were observed in the decreased blood flow responses elicited by cords soaked in physiological saline or other medicaments tested. Later, during the retraction procedure, however, microcirculation of the gingival margin appeared to depend on the medicament employed. Under the effect of physiological saline or astringents, perfusion returned near to the baseline level by the end of the fifth minute of the retraction period. Since the mechanical effects of the cord placed in the narrow sulcus prevailed continuously during this time, the increasing blood flow may reflect the local release of vasoactive mediators. This clinical study did not investigate the nature of these substances, but it is presumed that the metabolites released as a result of ischemia are most probably involved. Similar substances may induce increased blood flow responses after cord removal, which corresponds to post-ischemic reactive hyperemia. In contrast to the alterations in blood perfusion observed under the effects of astringents (and physiological saline), the decrease in blood flow after employing epinephrine prevailed during the ensuing five minutes, and continued over the entire observation period, with a transient instability after cord removal. This should reflect the predominance of the vasoconstrictor effect of epinephrine over the vasodilator mechanisms.

Epinephrine-impregnated retraction cords were widely used for some time in clinical practice (Donovan & others, 1985). Today, the popularity of this technique is declining. Several events have provided evidence that this drug may induce systemic responses such as elevation of arterial blood pressure, high pulse rate or even severe heart complaints in subjects with compromised cardiac function depending on the dose of epinephrine, the number of teeth involved in the gingival retraction procedure and the severity of gingival injury (Woycheshinn, 1964; Pelzner & others, 1978). Since operative and impression procedures immediately follow applying/removing the cord, a long-term ischemia, as produced in this study, may be unnecessary. Thus, it appears advisable to test the effects of lower doses of epinephrine, as well.

CONCLUSIONS

The results of this study suggest that the gingival ischemia required for adequate control of sulcular seepage and/or hemorrhage is probably provided by epinephrine-impregnated retraction cords. To avoid the systemic effect of epinephrine, the lowest effective dose is recommended. The laser Doppler flowmetry used in this clinical trial, in contrast to other clinical and histological observations, seems to be a suitable technique for assessment of microcirculatory changes in the gingival margin, and it may provide reliable data to select topically effective minimum dosages of vasoactive drugs

(Received 8 October 2001)

Acknowledgement

This study was supported by Research Grants from the Hungarian Scientific Research Found (OTKA T-023601), the Higher Education Research and Development Program (FKFP-B03/1997), the Scientific Research Council, Ministry of Welfare (ETT 30/2000) and the American Dental Concept (representation of Ultradent Product Inc in Hungary).

References

Buchanan WT & Thayer KE (1982) Systemic effects of epinephrine-impregnated retraction cord in fixed partial denture prosthodontics *Journal of the American Dental Association* **104(4)** 482-484.

Csempesz F, Vág J, Kerémi B, Györfi A & Fazekas Á (2000) Blood flow measurements in human oral tissues with laser Doppler flowmetry (in Hungarian) *Fogorvosi Szemle* **93(4)** 115-120.

Donovan TE, Gandara BK & Nemetz H (1985) Review and survey of medicaments used with gingival retraction cords *Journal of Prosthetic Dentistry* **53(4)** 525-531.

Fazekas Á, Csabai Z, Csempez F & Vág J (2000) Effect of retraction materials on the blood supply of gingival margin (in Hungarian) *Fogorvosi Szemle* **93(10)** 289-296.

de Gennaro GG, Landesman HM, Calhoun JE & Martinoff JT (1982) A comparison of gingival inflammation related to retraction cords *Journal of Prosthetic Dentistry* **47(4)** 384-386.

Harrison JD (1961) Effect of retraction materials on the gingival sulcus epithelium *Journal of Prosthetic Dentistry* **11(3)** 514-521.

Kerémi B, Csempesz F, Vág J, Györfi A & Fazekas Á (2000) Blood flow in marginal giniva as measured with laser Doppler flowmeter (in Hungarian) *Fogorvosi Szemle* **93(6)** 163-168.

Löe H (1967) The Gingival Index the Plaque Index and the Retention Index Systems *Journal of Periodontology* **38(5)** 610-616.

Mühlemann HR & Son S (1971) Gingival sulcus bleeding—a leading symptom in initial gingivitis *Helvetica Odontologica Acta* **15(3)** 107-113.

Nemetz H (1974) Tissue management in fixed prosthodontics *Journal of Prosthetic Dentistry* **31(6)** 628-636.

Nemetz H, Donovan T & Landesman H (1984) Exposing the gingival margin: A systematic approach for the control of hemorrhage *Journal of Prosthetic Dentistry* **51(5)** 647-651.

Pelzner RB, Kempler D, Stark MM, Lum LB, Nicholson RJ & Soelberg KF (1978) Human blood pressure and pulse rate response to racemic epinephrine retraction cord *Journal of Prosthetic Dentistry* **39(3)** 287-292.

Silness J & Löe H (1964) Periodontal disease in pregnancy II Correlation between oral hygiene and periodontal condition *Acta Odontologica Scandinavica* **22(2)** 121-135.

Woycheshinn, FF (1964) An evaluation of the drugs used for gingival retraction procedures *Journal of Prosthetic Dentistry* **14(4)** 769-776.

©Operative Dentistry, 2002, **27,** 349-353

Fracture Resistance of Premolars with Bonded Class II Amalgams

GM Dias de Souza • GDS Pereira
CTS Dias • LAMS Paulillo

Clinical Relevance

The bonding amalgam technique using Scotchbond Multi-Purpose Plus increased the fracture resistance of maxillary premolars with retentive preparations, and Panavia F cement did not present better results than the group restored only with silver amalgam.

SUMMARY

This study evaluated the fracture resistance of maxillary premolars with MOD cavity preparation and simulated periodontal ligament. The teeth were restored with silver amalgam (G1), Scotchbond Multi-Purpose Plus and silver amalgam (G2) and Panavia F and silver amalgam (G3). After restorations were made, the specimens were stored at 37ºC for 24 hours at 100% humidity and submitted to the compression test in the Universal Testing Machine (Instron). The statistical analysis of the results (ANOVA and Tukey Test) revealed that the fracture resistance of group 2 (G2=105.720 kgF) was superior to those of groups 1 (G1=72.433 kgF) and 3 (G3=80.505 kgF) that did not differ between them.

*Grace Mendonça Dias de Souza, DDS, graduate student, Department of Restorative Dentistry, State University of Campinas, School of Dentistry

Gisele Damiana da Silveira Pereira, DDS, MS, PhD, professor of Restorative Dentistry, Gama Filho University

Carlos Tadeu dos Santos Dias, DDS, MS, PhD, assistant professor of Statistics Mathematics, University of São Paulo

Luis Alexandre Maffei Sartini Paulillo, DDS, MS, PhD, associate professor, Department of Restorative Dentistry, State University of Campinas

*Reprint request: Av Limeira, 901, Bairro Areiáo, Piracicaba, São Paulo, Brasil-13414-018; e-mail: paulillo@fop.unicamp.br

INTRODUCTION

Silver amalgam, used in dentistry since 1826 (Staninec & Holt, 1988), is still frequently used to restore proximo-occlusal cavities in posterior teeth due to its favorable properties, easy handling characteristics and obtaining of appropriate proximal contacts (Gwinnett & others, 1994). However, one of the disadvantages of the extensive restorations in amalgam is that, since it does not stick to the dental structure, it does not reinforce the weak walls of the cavity (Jagadish & Yogesh, 1990; Oliveira, Cochran & Moore, 1996) and they need retentive walls or additional mechanical retentions, such as posts, pins or grooves for their stability, reducing the healthy tooth structure and, consequently, weakening the tooth (Staninec & Holt, 1988; Staninec, 1989; Gwinnett & others, 1994).

Amalgam cannot reinforce weak walls because of its low resilience and high modulus of elasticity. Therefore, it is necessary to remove the enamel with no support of dentin in order to reduce the possibility of coronary fracture (El-Sherif & others, 1988). This is evidenced by the fact that 13% of the amalgam restoration replacements are due to the fracture of cusps (Lagouvardos, Sourai & Douvitsas, 1989; Boyer & Roth, 1994; Pilo, Brosh & Chweidan, 1998). The anatomic form of posterior teeth with cusps and fossae present a design with a tendency to deflect the cusps under stress (Joynt & others, 1987; Mondelli & others, 1980); however, secondary decay, abrasion or erosion and extensive preparations also predispose the tooth to fracture (Khers & others, 1990) because removing the marginal ridge and increasing the isthmus occlusal width considerably weakens the tooth (Mondelli & others, 1980; Joynt & others, 1987; Lagouvardos & others, 1989; Pilo & others, 1998).

Denehy & Torney (1976) and Santos & Meiers (1994) proposed using adhesive materials, aiming to reinforce the coronary structure (Denehy & Torney, 1976; Santos & Meiers, 1994). The union agent applied to the conditioned dental surface prior to amalgam insertion seems to increase the fracture resistance of posterior teeth (Joynt & others, 1987). The technique consists of amalgam condensation on the uncured adhesive, generating an ionic and mechanical adhesion between the etched tooth surface and the adhesive resin and a mechanical interlocking and adhesion mediated by Van der Walls forces between the adhesive resin and amalgam that explain the possible increase in the fracture resistance of teeth weakened by the cavity preparation (Staninec & Holt, 1988; Gwinnett & others, 1994; Pilo & others, 1998).

The technical difficulties, increase of clinical time and cost of the procedure are limitations of the technique that justify studies to evidence the benefits stated in the literature (Khers & others, 1990; Boyer & Roth, 1994; Christensen, 1994).

This work evaluated the fracture resistance of maxillary premolars with mesio-occlusol-distal cavity preparations and convergent walls restored with the adhesive amalgam technique.

METHODS AND MATERIALS

Twenty-four non-carious recently extracted maxillary premolars were stored in 10% formalin solution (pH=7.0) at room temperature for no longer than one month. After they had been cleaned with periodontal curettes, the teeth received a radicular covering with wax (n° 7) in order to form a 0.3 mm thick film controlled with digital caliper (Digimess, São Paulo, Brazil 01415-021), corresponding to the periodontal ligament space (Coolidge, 1937).

The roots were inserted in polystyrene resin cylinders, exposing 2 mm of the root surface below the cementum-enamel junction. Next, the wax that occupied the 0.3 mm space was removed with hot water and substituted by urethane rubber material (PU-501/Nexus–SEM TOGO), São Paulo, Brazil 01349-518) which, besides simulating the periodontal ligament, fastens the root in its artificial alveolus (Sharnagl, 1998).

The intercuspal distance in the occlusal surface and the height of the buccal cuspid top to the enamel-cementum junction of each tooth were measured using a digital caliper to standardize the cavity preparations.

MOD cavities were prepared with convergent walls with no approximal boxes, using a diamond bur FG 3145 (KG Sorensen, Barueri, Brazil 01981-340) in a high-speed water cooler handpiece fixed in a specially designed jig (Figure 1). This device is also constituted by an apparatus that standardizes the cavity preparation by holding the cylinders where the teeth were included, and allowing its buccol-lingual and mesio-distal accurate movements (0.001 mm) in order to make the cavities with the dimensions previously established. The isthmus width was 3/5 the distance between the cusp tips, and the pulpal depth was 3/5 the height of the crown. Soon afterwards, a diamond bur FG 1016 (KG Sorensen) was positioned tangent to the floor of the preparation penetrating about 1 mm in the base of the buccal and lingual cusps in order to weaken them. The width of the cavity preparation was checked in the occlusal portion and the pulpal depth was measured regarding buccal cusp top with a digital caliper. The preparations were finished with the same diamond bur (FG 3145) in a low-speed handpiece (Figure 2). The teeth were rinsed with an air-water spray, then randomly divided into three groups (n=8). Group 1: teeth restored with silver amalgam using alloy Permite C (SDI, São Paulo, Brazil 05421-030) and the conventional restoration technique (Gwinnett & others, 1994). Group 2: dentin adhesive system Scotchbond Multi-

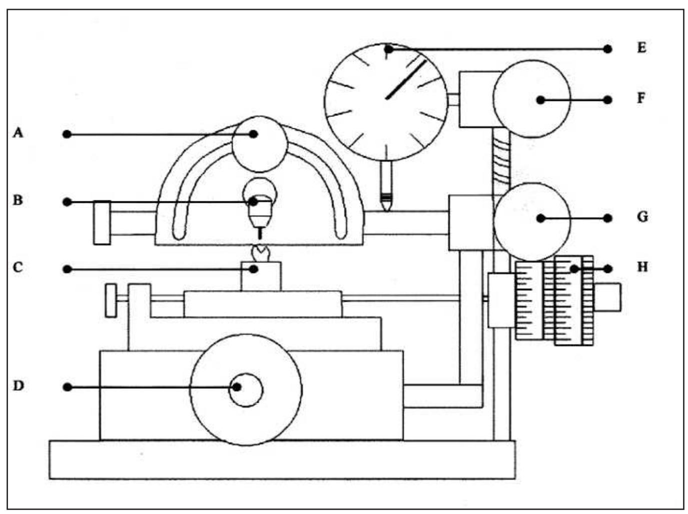


Figure 1. *Precision instrument utilized to prepare the cavities: A diagram.*
A: Screw that controls high speed bending.
B: High-speed water cooler handpiece positioned.
C: Premolar in polyestirene cylinder resin.
D: Instrument that moves the sample in the mesio-distal direction.
E: Precision instrument that regulates the depth of the preparation.
F: Screw that controls the position of the depth controller.
G: High-speed controller.
H: Instrument that moves the sample in the buccol-lingual direction.

Figure 2. *Aspect of MOD cavity preparation before restoration.*

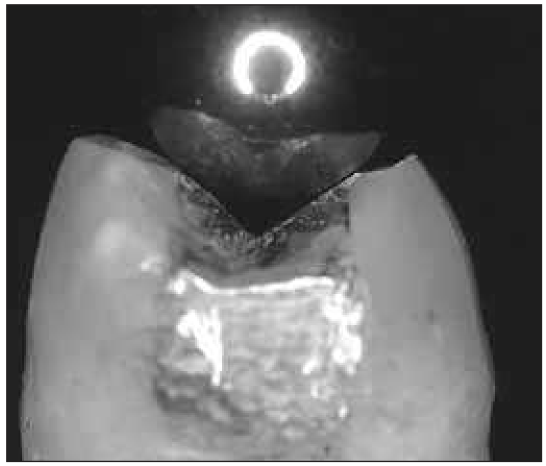


Figure 3. *Steel sphere to provide oclusal loading on the cusps.*

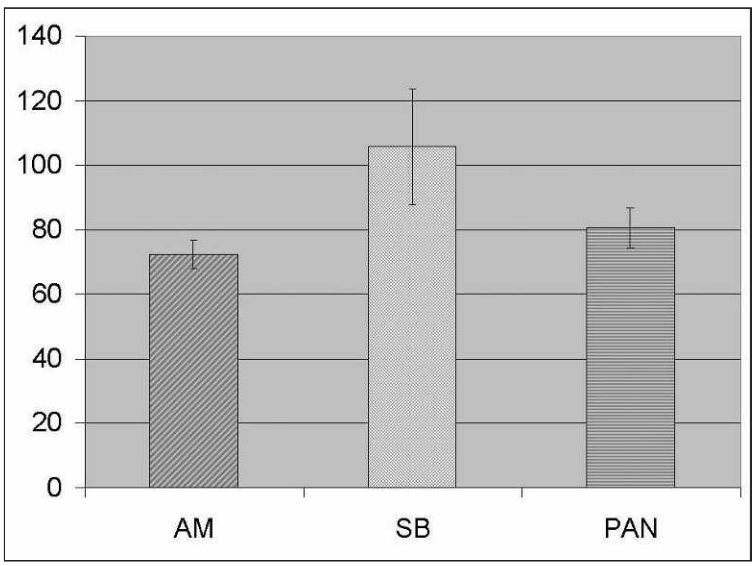


Figure 4. *: Illustrative graphic of means and standard deviations for the fracture resistance test.*
AM: Silver amalgam
SB: SBMP Plus and silver amalgam
PAN: Panavia F and silver amalgam

Purpose Plus (SBMP Plus–3M Dental Products, Campinas, Brazil 13001-970) was applied before the insertion of the amalgam. Group 3: resin cement Panavia F (Kuraray Co, Osaka, Japan 1-12-39) was used before the teeth were restored with Permite C. The bonding agents' components used in the adhesive amalgam technique were applied according to manufacturer's instructions.

The specimens were stored for 24 hours in 100% relative humidity at 37°C and the fracture test was conducted in an Instron testing machine (Instron Corp, Canton, England 02021-1089) with 500 Kgf load. A 4 mm diameter steel sphere contacted the buccal and lingual cusps of the tested teeth at a crosshead speed of 0.5mm/min, until fracture occurred (Figure 3).

RESULTS

The results obtained in this study are presented in Table 1. The mean values for the three groups were: G1-72.433 kgf; G2-105.720 kgf; G3-80.505 kgf. ANOVA test was made and showed significant statistical differences among the groups. Tukey test, α=0.05, was used to compare the statistical differences among the experimental groups, and its results are showed in Table 1 and Figure 4. Analyzing Table 1, the Tukey test presents the following results: SB presented the highest bond strength means that was statistically different from the other groups; AM and PAN presented statistically similar values.

DISCUSSION

Employment of adhesive systems under amalgam restorations is due to the immediate reduction of the marginal leakage (Varga, Matsumara & Masuhara, 1986; Simizu, Ui & Kawakami, 1987; Caron & others, 1996), capacity of amalgam retention in the cavity, what makes possible the accomplishment of cavity preparations with no mechanical retentions, preserving dental structure (Lacy & Staninec, 1989; Staninec, 1989; Charlton, Moore & Swartz, 1992) and the immediate reduction of the postoperative sensibility (Fusayama & others, 1979; Lacy & Staninec, 1989; Trushkowsky, 1991).

On the other hand, coronary fractures in posterior teeth with wide cavities are not rare in dental practice (Lagouvardos & others, 1989; Khers & others, 1990) and, according to Mondelli & others (1980), the most frequent causes of this fracture type are the inadequate manipulation of the restorative material and the geometric form of the preparation, due to the minute amount of the remaining dental structure. Cavity preparations with parallel walls and width of 2/5 of the intercuspidal distance were restored by the adhesive amalgam technique, and there was no significant difference among the appraised groups (silver amalgam; SBMP and amalgam; Panavia F and amalgam), probably due to the significant amount of remaining dentin under the cusps, providing them support and flexibility during the experiment (Dias de Souza & others, 2001). Therefore, in order to accomplish this work, in this study, this cavity preparation was idealized with

Table 1: *Means and Standard Deviations for the Fracture Resistance Test*

Treatment	Mean	Tukey Grouping
Amalgam (AM)	72.433 (±4.357)	A
Scotchbond MP Plus (SB)	105.720 (±17.996)	B
Panavia (PAN)	80.505 (±6.206)	A

Significant differences between SB and the others (p>0.05) by Analysis of Variance.

a spherical diamond bur tangent to the floor and the dentin structure was removed to weaken the cusps, aiming to simulate a real clinical situation. Besides, Gelb, Barouch & Simonsen (1986) stated that the larger the width of the preparation, the smaller the tooth resistance. Therefore, the preparations were made with a width of 3/5 of the intercuspidal distance and removal of the marginal crests.

The statistical analysis revealed no significant statistical difference among the fracture resistance values for the groups restored with amalgam (AM) and Panavia F and amalgam (PAN), but these were significantly smaller than the values found for the group restored with SPMP Purpose Plus and silver amalgam (SB). These results differ from those found in the work of Pilo & others (1998), in which the smallest fracture resistance values were presented by the group restored with SBMP Plus and the authors attributed that to the absence of filler particles. However, this study's result agrees with Mishell, Share & Nathanson (1984), who found larger fracture resistance in the group restored with adhesive for enamel and dentin and amalgam than in the group restored only with amalgam. Chalkley & Jensen (1984) explained that when adhesives for enamel and dentin are applied on a previously conditioned surface, the union force of the restorative material to the tooth is twice as large as when there is no application of those systems. Besides, this larger resistance is due to the extensive available area for adhesion inside the preparation (Eakle, 1986). Another important factor is that the adhesive of the SBMP Plus system presents high resilience as a result of the filler absence and also has the capacity to form a thicker, uniform hybrid layer that results in reliable adhesion values, reinforcing the dental crown (Söderholm, 1997).

The low fracture resistance values for the group restored with Panavia F and amalgam were probably related to the self-etching primer supplied by the manufacturer. The acidic monomers of this primer dissolve and incorporate the smear layer into the mixture as it also demineralizes the superficial dentin and encapsulates the collagen fibers and the hydroxyapatite crystals (Nishida & others, 1993; Gordan & others, 1998). This union mechanism presents satisfactory initial values of adhesion; however, the superficial penetration of the adhesive results in a slightly thicker hybrid layer with high modulus of elasticity, reducing the capacity to absorb loads and the reinforcement capacity (Uno & Finger, 1996). It is also known that, below the hybrid layer, an area of brittle dentin is formed by the continuous conditioning, which could damage the adhesion values in 24 hours (Söderholm, 1997).

On the other hand, the cement Panavia F was supposed to provide elasticity to the cavity walls, increasing the fracture resistance. However, this cement possesses a high amount of filler, increasing its modulus of elasticity, which reduces its capacity to absorb tensions (Eliades, 1994; Phrukkanon, Burrow & Tyas, 1998).

It is important to point out that making restorations using Panavia F in the technique of the adhesive amalgam presents difficulties since there is no control on the amount of cement inserted in the cavity, and the cement excess tends to adhere to the condenser and to extravasate the cavity, hindering the finalization of the restoration, which increases the clinical time and promotes a rough surface in the cervical third of the restoration. This could lead to future problems (Mahler & others, 1996).

For this reason, the authors can state that, in teeth weakened by wide cavity preparations, it is interesting to apply a union system that makes use of total conditioning of dental surface and adhesive for enamel and dentin such as SBMP Plus, prior to the amalgam insertion, aiming to prevent dental fracture.

CONCLUSIONS

Based on the results found in this study, the authors can conclude that SBMP Plus, associated with the silver amalgam, increased the fracture resistance of maxillary premolars with wide cavity preparations and convergent walls when compared to the groups restored only with amalgam or with Panavia F associated to the silver amalgam. Therefore, it may be important for clinicians to evaluate the tooth condition, applying adhesives in the cavity preparations whenever the tooth presents considerable weakening.

Acknowledgements

The authors are grateful to Kuraray Co for donating the material employed in this study.

(Received 28 August 2001)

References

Boyer DB & Roth L (1994) Fracture resistance of teeth with bonded amalgams *American Journal of Dentistry* **7** 91-94.

Christensen GJ (1994) Should you and can you afford to bond amalgams? *Journal of the American Dental Association* **125(10)** 1381-1383.

Caron GA, Murchison DF, Cohen RB & Broome JC (1996) Resistance to fracture of teeth with various preparations for amalgam *Journal of Dentistry* **24(6)** 407-410.

Chalkley YM & Jensen ME (1984) Enamel shear bond strengths of a dentinal bonding agent *IADR* **62** Abstract #467.

Charlton DG, Moore BK & Swartz ML (1992) *In vitro* evaluation of the use of resin liners to reduce microleakage and improve retention of amalgam restorations *Operative Dentistry* **17(3)** 112-119.

Coolidge ED (1937) The thickness of human periodontal membrane *Journal of the American Dental Association* **24** 1260-1270.

Denehy GE & Torney DL (1976) Internal enamel reinforcement through micromechanical bonding *Journal of Prosthetic Dentistry* **36(2)** 171-175.

Dias De Souza GM, Pereira GDS, Dias CTS & Paulillo LAMS (2001) Fracture resistance of teeth restored with the bonded amalgam technique *Operative Dentistry* **26(5)** 511-515.

Eakle WS (1986) Fracture resistance of teeth restored with class II bonded composite resin *Journal of Dental Research* **65(2)** 149-153.

Eliades G (1994) Clinical relevance of the formulation and testing of dentine bonding systems *Journal of Dentistry* **22(2)** 73-81.

El-Sherif MH, Halhoul MN, Kamar AA & Nour El-Din A (1988) Fracture strength of premolars with class 2 silver amalgam restorations *Operative Dentistry* **13(2)** 50-53.

Fusayama T, Nakamura M, Kurosaki M & Iwaku M (1979) Non-pressure adhesion of a new adhesive restorative resin *Journal of Dental Research* **58(4)** 1364-1370.

Gelb MN, Barouch E & Simonsen RJ (1986) Resistance to cusp fracture in Class II prepared and restored premolars *Journal of Prosthetic Dentistry* **55(2)** 184-185.

Gordan VV, Vargas MA, Cobb DS & Denehy GE (1998) Evaluation of acidic primers in microleakage of Class 5 composite resin restorations *Operative Dentistry* **23(5)** 244-249.

Gwinnett AJ, Baratieri LN, Monteiro S Jr & Ritter AV (1994) Adhesive restorations with amalgam: Guidelines for the clinician *Operative Dentistry* **25(10)** 687-695.

Jagadish S & Yogesh BG (1990) Fracture resistance of teeth with Class II silver amalgam, posterior composite and glass cermet restorations *Operative Dentistry* **15(2)** 42-47.

Joynt RB, Wieczkowski G Jr, Klockowski R & Davis EL (1987) Effects of composite restorations on resistance to cuspal fracture in posterior teeth *Journal of Prosthetic Dentistry* **57(4)** 431-435.

Khers SC, Carpenter CW, Vetter JD & Staley RN (1990) Anatomy of cusps of posterior teeth and their fracture potential *Journal of Prosthetic Dentistry* **64(2)** 139-147.

Lacy AM & Staninec MA (1989) The bonded amalgam restoration *Quintessence International* **20(7)** 521-524.

Lagouvardos P, Sourai P & Douvitsas G (1989) Coronal fractures in posterior teeth *Operative Dentistry* **14(1)** 28-32.

Mahler DB, Engle JH, Simms LE & Terkla LG (1996) One-year clinical evaluation of bonded amalgam restorations *Journal of the American Dental Association* **127(3)** 345-349.

Mishell Y, Share J & Nathanson D (1984) Fracture resistance of Class II amalgam vs light activated composite restorations *in vitro Journal of Dental Research* **63(Special Issue)** Abstract #1099, pg 293.

Mondelli J, Steagall L, Ishikiriama A, Navarro MFL & Soares FB (1980) Fracture strength of human teeth with cavity preparations *Journal of Prosthetic Dentistry* **43(4)** 419-422.

Nishida K, Yamaushi J, Wada T & Hosoda H (1993) Development of a new bonding system *Journal of Dental Research* **72** Abstract #267 p 137.

Oliveira J, Cochran MA & Moore BK (1996) The influence of bonded amalgam restorations on the fracture strength of teeth *Operative Dentistry* **21(3)** 110-115.

Phrukkanon S, Burrow MF & Tyas MJ (1998) Effect of cross-sectional surface area on bond strength between and dentin *Dental Materials* **14(2)** 120-128.

Pilo R, Brosh T & Chweidan H (1998) Cusp reinforcement by bonding amalgam restorations *Journal of Dentistry* **26(5-6)** 467-472.

Santos AC & Meiers JC (1994) Fracture resistance of premolars with MOD amalgam restorations lined with Amalgambond *Operative Dentistry* **19(1)** 2-6.

Sharnagl P (1998) Simulation der physiologischen zahnbeweglichkeit bei der *in-vitro*-belastungsprüfung dentaler restaurationen im "Resenburger Kausimulator" Untersuchung am beispiel volkeramischer In-Ceram-Brücken. [*Inaugural Dissertation zur Erlangung des Doktorgrades der Zahnheilkunde der Medizinischen Fakultät der Universität Resenburg*.]

Simizu A, Ui T & Kawakami M (1987) Microleakage of amalgam restoration with adhesive resin cement lining, glass ionomer cement base and fluoride treatment *Dental Materials* **6(1)** 64-69.

Söderholm KJM (1997) Technique sensitivity of dentin bonding *General Dentistry* **45(3)** 218-222.

Staninec M (1989) Retention of amalgam restorations: Undercuts versus bonding *Quintessence International* **20(5)** 347-351.

Staninec M & Holt M (1988) Bonding of amalgam to tooth structure: Tensile adhesion and microleakage tests *Journal of Prosthetic Dentistry* **59(4)** 397-402.

Trushkowsky R (1991) Restoration of a cracked tooth with a bonded amalgam *Quintessence International* **22(5)** 397-400.

Uno S, Finger WJ (1996) Effects of acidic conditioners on dentin demineralization and dimension of hybrid layers *Journal of Dentistry* **24(3)** 211-216.

Varga J, Matsumara H & Masuhara E (1986) Bonding of amalgam filling to tooth cavity with adhesive resin *Dental Materials* **5(2)** 158-164.

©Operative Dentistry, 2002, **27**, 354-359

In Vitro Surface Analysis of Active and Arrested Dentinal Caries Using a pH-Imaging Microscope

Y Kitasako • N Hiraishi • M Nakajima
T Nikaido • J Tagami • S Nomura

Clinical Relevance

A pH analysis technique might be a diagnostic adjunct for classifying dentinal caries lesions as active or arrested.

SUMMARY

This *in vitro* **study evaluated the pH value of active and arrested caries lesions in deep dentinal caries using a pH-imaging microscope (SCHEM-100, HORIBA Ltd, Kyoto, Japan). Buccal-lingual cut sections of extracted human teeth that had either active or arrested dentinal caries lesions were placed on the pH-imaging sensor of the microscope. The pH values were compared statistically by one-way ANOVA and Fisher's PLSD test (p<0.05). In addition, both types of caries lesions were compared with a caries detector solution for this pH-imaging characterization. For both active and arrested lesions in dentin, the lowest pH values in the caries lesions (range from 5.3 to 6.6) were lower than that of intact dentin (range from 6.8 to 7.4). There were statistical differences between the lowest pH value within the active lesion (range from 5.3 to 5.8) and the arrested lesion (range from 6.3 to 6.6) (p<0.05). Although the arrested lesion was unstainable and impermeable to the dye, there was a close relationship between dye staining and pH-imaging characterization within the active lesion from visual inspection.**

*Yuichi Kitasako, research associate, Tokyo Medical and Dental University

N Hiraishi, graduate student, Tokyo Medical and Dental University

M Nakajima, instructor, Tokyo Medical and Dental University

T Nikaido, lecturer, Tokyo Medical and Dental University

J Tagami, professor and chairman, Tokyo Medical and Dental University

S Nomura, manager, R&D Center, Horiba Ltd, Kyoto, Japan

*Reprint request: Cariology and Operative Dentistry, Department of Restorative Sciences, Graduate School, Tokyo Medical and Dental University, 5-45 Yushima 1-chome, Bunkyo-ku, Tokyo 113-8549, Japan; e-mail: y.kitasako.odnt@dent.tmd.ac.jp

INTRODUCTION

Caries is a dynamic process whereby mineral is removed during exposure to an acidic environment and replaced if the environment is restored to a neutral pH level. In the clinical situation, a tooth surface may suffer cariogenic challenges that produce demineralization interspersed with relatively long periods of exposure to saliva that allows for remineralization of the demineralized tooth surface. On the other hand, carious lesions can be classified, based on their clinical and gross histological characteristics, into three groups: active, arrested and mixed lesions (Massler, 1945; Miller & Massler, 1962). An arrested dentinal lesion differs from an active lesion. Sometimes it is darkly stained and there may be an absence of viable bacteria within the tubules, impermeability to dyes and isotopes and a higher calcium content and hardness (Parikh, Massler & Bahn, 1963; Young & Massler, 1963; Barber & Massler, 1964; Lynch & Beighton, 1994). Young & Massler (1963) indicated that arrested dentinal lesions were more resistant to proteolytic enzyme attack than active dentinal lesions.

Table 1

	Active Carious Group	Arrested Carious Group
Age	mainly young children or adolescents (from 19 to 28 in this study)	older age (from 35 to 57 in this study)
Surface	Soft and friable	Hard and leathered
Color	Pale brown	Darkly pigmented
Pain	Present on stimulation with probe and/or hot and cold air	None

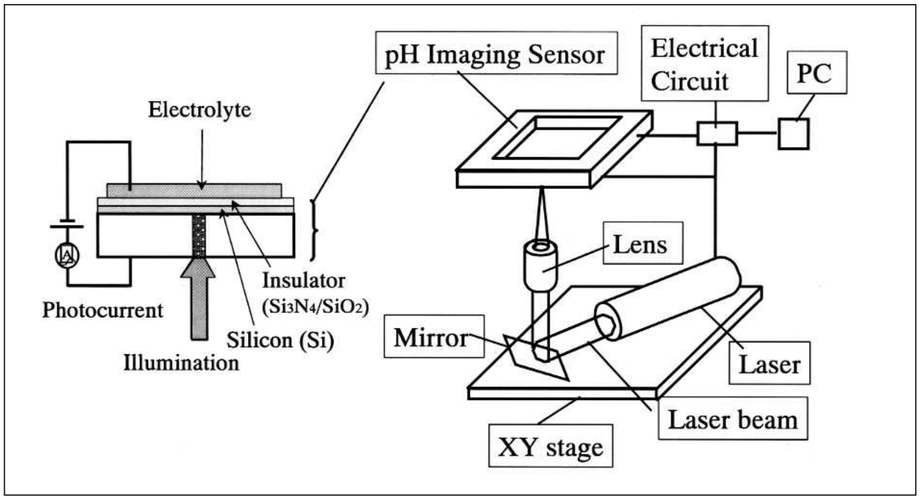


Figure 1. *pH measurement principle and instrument set-up.*

The pH measurement using a glass electrode has been widely used for dental plaque pH measurements (Stephan & Miller, 1943; Stephan, 1944). Recently, a new pH-imaging microscope (SCHEM-100, HORIBA Ltd, Kyoto, Japan) based on a semiconductor silicon sensor has been developed (Nomura & others, 1997). The pH distribution formed in a thin agar film can be measured quantitatively, and a pH-dependent electric signal at each measurement point is converted and displayed as a pH image. The pH-imaging sensor is based on photocurrent characteristics of semi-conductor silicon (Hafeman, Parce & McConnell, 1988). The characteristics enable the sensor to work as an array of multiple sensing parts, although it is a single solid sensor with a flat, uniform sensing surface. The pH values obtained by the sensor at each pH-measurement point are converted to a gray scale pixel, and the color scale of each pH value is displayed as pH images. By taking advantage of the sensor's flat pH-sensing surface and capability of multiple-point pH measurement, a new concept of performing the surface chemical analysis of a solid sample has been established. Applying this surface analysis to the evaluation of a relatively solid surface of a biological sample, such as a plant leaf, has been demonstrated (Nomura & others, 2000). Kitasako & others (2000) reported that the pH distribution of carious dentin was lower than that of intact dentin using this pH-imaging microscope. Although there are many pH profile studies on dental plaque on enamel (Stephan, 1944; Sanaone & others, 1993), pH changes in carious dentin are not well understood.

To understand the nature of the carious process, including active and arrested lesions, it is important to investigate whether areas of varying pH exist in dentin. This study evaluated the pH value of active and arrested carious lesions in deep dentinal caries using this pH-imaging microscope. In addition, both types of carious lesion were compared using a dye solution for the pH-imaging characterization.

METHODS AND MATERIALS

Samples

Twenty extracted human molars with moderate-to-severe dentin caries lesions on the occlusal surfaces were used for this study. The teeth were obtained from patients who consented verbally to using their teeth for research and educational purposes. The teeth were stored frozen to keep the micro-organisms alive after extraction until the experimental procedure. Twenty samples were classified into two groups (n=10); the active caries group or arrested caries group. In this study, the clinical criteria of a soft surface layer and sharp pain when subjected to a thermal stimulus of a blast of cold air were used to define active (Miller & Massler, 1962), while a hard, leathery surface and dark pigmentation were associated with arrested caries (Table 1).

Sample Preparation

The occlusal surfaces were initially photographed using a stereomicroscope (PM-10AK, Olympus Optical Corp, Tokyo, Japan) at a magnification of x15. The teeth were sectioned at the cemento-enamel junction with a high-speed diamond bur under water-cooling. The root was discarded and the crown portion mounted on an acrylic rod with cyanoacrylate adhesive (Zappit, DVA Corp, Corona, CA 91719, USA) for vertical sectioning. Three 1 mm-thick buccal-lingual sections were then prepared through the center portion of the tested lesion. The sectioned surfaces were finished with 600-grit silicon carbide paper under running water for 10 strokes, then photographed at a magnification of x15.

pH-Imaging Sensor

The pH-imaging sensor is a flat semiconductor sensor with a sensing area of 2.5 cm x 2.5 cm. This sensor functions as an array of multiple sensing parts, though it is a single monolithic sensor with a flat sensing surface. The spatial resolution and the pH resolution of the sensor are 100 µm and 0.1 pH, respectively. The sensor is based on Light Addressable Potentiometric Sensor (Hafeman & others, 1988) made of Si_3N_4/SiO_2 upper layer and a Silicon (Si) lower layer as depicted in Figure 1. The Si_3N_4 layer is proton-sensitive and contacts an electrolyte. A light beam is directed from the Si side with a bias voltage applied between the electrolyte and the Si side. The characterization of the AC photocurrent induced by the modulated illumination from the Si side depends on the amount of protons at the Si_3N_4 surface, thus enabling pH measurement to be made. Since this sensor can only detect protons located in the illuminated region, this single monolithic sensor can function as if it were divided into an array of small independent sensors by focusing and scanning the light illumination. The pH dependent photo-current at each measurement point is fed to a PC. The current is converted to a gray scale pixel and each pixel is arranged to the pH imaging using image analysis software (Image Pro Plus, Media Cybernetics, Silver Springs, MD 20910, USA).

Surface Acid/Base Characterization Using pH-Imaging Sensor

Figure 2 shows the experimental setup for the surface acid/base characterization using a pH-imaging sensor. A 1 mm-thick agar film is sandwiched between the sensor and the test surface of a human tooth sample. Acid and/or base adhered to the sample surface or acid and/or base contained inside the sample are released into the agar film, generating the pH distribution in the agar film. The pH measurement at multiple points on the bottom of the agar film is conducted, then the pH distribution is displayed as pH images. Although the pH distribution to be obtained is that formed at the bottom of the agar film, this pH distribution reflects the distribution of acidic and/or base on the surface of the tested sample. Therefore, the surface of the sample can be chemically characterized. In this study, the sectioned surface of the extracted tooth was placed on a thin agar film (pH 7.0) to evaluate the pH distribution. When the sample contacts the agar film, it generates a pH distribution depending on the amount of H^+ or OH^- on the sample surface (Figure 2).

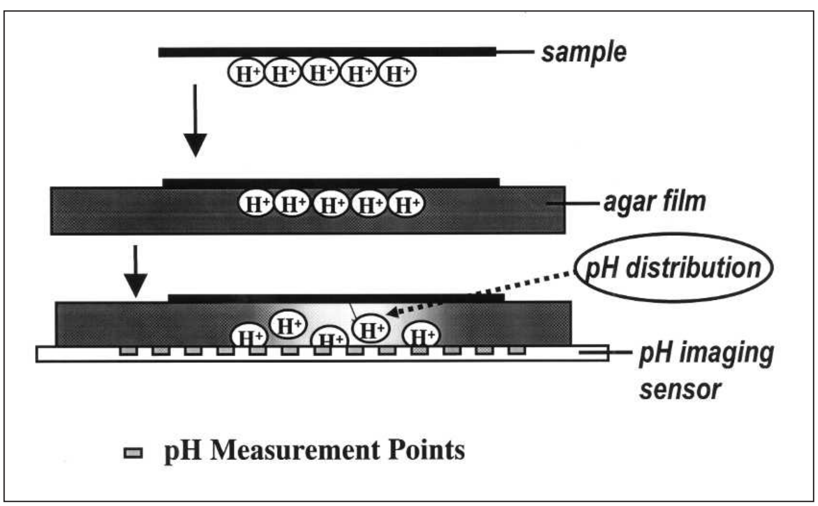


Figure 2. *Surface acid/base characterization using pH-imaging sensor.*

Evaluate the pH Distribution Using pH-Imaging Microscope

The gray scale of each pixel that makes up the image can be correlated to the pH value at each measurement point. Therefore, the pH value composing the pH image can be examined using computer software (Excel, Microsoft Corp, Redmond, WA 98052, USA). The caries or intact dentinal lesion was classified using this pH-imaging analysis as follows: the area of lowest intensity grayness was determined as the caries lesion; the highest intensity was the intact lesion (Kitasako & others, 2000). For each sample, the pH line profile including intact and carious dentin was measured three times. The lowest pH value of active and arrested caries lesions in dentin were compared statistically to distinguish significant differences by one-way ANOVA and Fisher's PLSD test (Siegel & Castellan, 1988).

Caries Detection Dye

After pH analysis, the cut surface was stained for 30 seconds by a caries-detection dye (Caries Detector Kuraray Corp, Osaka, Japan). Following washing and air drying of the cut surface, the stained surfaces were photographed at a magnification of x15. Then, the relationship between the caries detector staining pattern and the pH characterization of the carious dentin was examined by visual inspection to compare the outline and distinguish the caries-affected area from the intact area.

RESULTS

In this study, the average ages of the active and arrested caries group were 23.2 and 48.5, respectively (Table 2). Figures 3 and 4 are representative pH images and pH line profiles of active and arrested caries lesions, respectively. For the pH-imaging analysis, the pH line profile, including intact and caries dentinal lesions, were measured three times for each sample. The caries or intact dentinal lesion

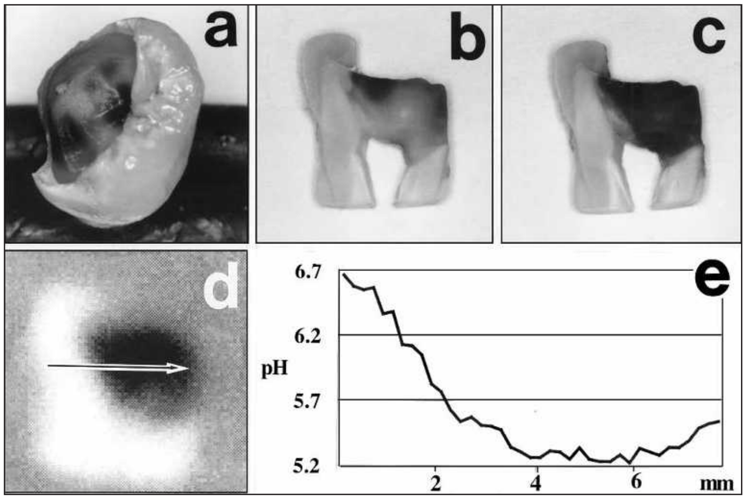


Figure 3. *Active caries (age: 23, man, 18).*
(a) sample. (b) sliced surface. (c) caries detector staining.
(d) pH imaging. The area of lowest intensity grayness was determined as the caries lesion; the highest intensity was the intact lesion. The pH line profile including intact and caries dentin was measured (arrow). (e) pH line profile data as shown in Figure 3d (arrow).

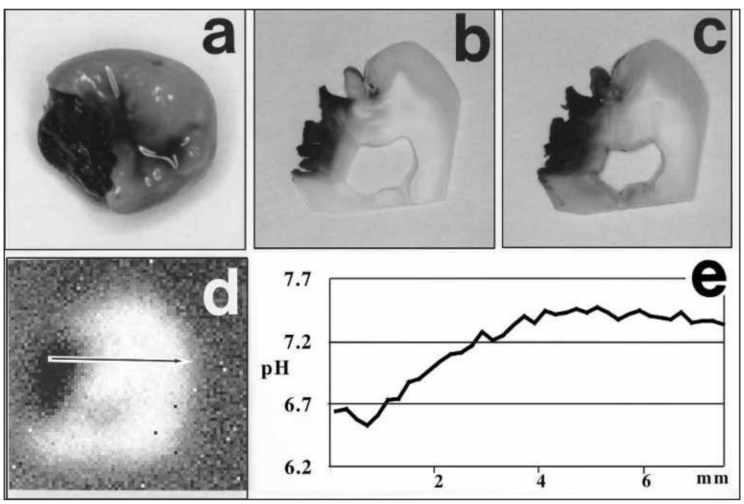


Figure 4. *Arrested caries (age: 43, man, 48).*
(a) sample. (b) sliced surface. (c) caries detector staining.
(d) pH imaging. The area of lowest intensity grayness was determined as the caries lesion; the highest intensity was the intact lesion. The pH line profile including intact and caries dentin was measured (arrow). (e) pH line profile data as shown in Figure 4d (arrow).

was classified using this pH-imaging analysis as follows: the area of lowest intensity grayness was determined as the caries lesion; the highest intensity was the intact lesion. The pH value of both the active lesions (range from 5.3 to 5.8) and the arrested lesions (range from 6.3 to 6.6) were less than those of intact dentin (range from 6.8 to 7.4). There were statistical differences between the lowest pH values of the active lesion (range from 5.3 to 5.8) and that of the arrested lesion (range from 6.3 to 6.6) ($p<0.05$). The lowest pH point was always detected at the inner region from the periphery of pH-imaging carious characterization.

Although the arrested lesion could not be stained and was impermeable to the dye, the visual inspections of the dye staining area and the pH-imaging area within the active lesion in dentin resembled each other (Figure 3 and 4). Even under the dark pigmentation of the arrested lesion, this pH-imaging characterization has the potential to aid in assessing carious lesions.

DISCUSSION

The total amount of H^+, calculated from pH, has been used by many workers as a measure of plaque (Stephan & Miller, 1943; Stephan, 1944; Igarashi, Kamiyama & Yamada, 1981). Brown, Patel & Chow (1975) suggested that an accelerated carious formation occurs due to a prolonged period of low pH. Therefore, pH distribution within the caries affected area is an important factor for indicating caries activity. In this study, the pH distribution formed in a thin agar film can be measured quantitatively. Since a 1 mm-thick agar film is sandwiched between the sensor and the test surface of samples, the measured pH distribution that was generated in the agar film was an indirect representation of the *in vitro* tested tooth. Using this method of pH analysis, it is possible to detect acid and/or base contained within the sample and on the surface. A pilot study revealed that different methods of surface preparation (600 grid, 1,000 grid silicon carbide paper and diamond polishing paste) did not affect the subsequent pH analysis. In this pH measurement method, acid and/or base adhered to the sample surface or acid and/or base contained inside the sample are released into the agar film but not washed away during sectioning. Further study regarding the sensitivity of the tested agar is required to investigate the sampling affect on pH value.

For intact dentin, the lowest pH value showed as a neutral value (range from 6.8 to 7.4). On the other hand, for both active and arrested lesions in dentin, the lowest pH values (range from 5.3 to 6.6) were less than that of intact dentin (range from 6.8 to 7.4). There were statistical differences between the lowest pH values of the active lesion (range from 5.3 to 5.8) and the arrested lesions (range from 6.3 to 6.6) ($p<0.05$). These pH differences between active and arrested lesions in dentin might suggest different properties of decalcification within the peritubular dentin or intertubular dentin (Mechanic, 1971), the denaturation of intratubular protoplasm (Ogawa & others, 1983) and debris from dental plaque micro-organisms (Parikh & others, 1963; Barber & Massler, 1964; Van Houte & others, 1991; Sanaone & others, 1993). The decalcification and proteolytic processes that take place during

Table 2: *Lowest pH Value*

Active Caries Group

Sample	Age (Average: 23.2)	Sex	Two-Digit System	Caries Lowest pH	Intact pH
1	19	man	28	5.3	6.8
2	21	man	27	5.5	6.9
3	21	female	18	5.6	7.0
4	22	man	28	5.4	6.9
5	22	man	18	5.8	7.0
6	23	man	18	5.3	6.8
7	25	man	17	5.4	6.8
8	25	female	48	5.4	6.8
9	26	man	36	5.8	7.3
10	28	female	38	5.8	7.0

Arrested Caries Group

Sample	Age (Average: 48.5)	Sex	Two-Digit System	Caries Lowest pH	Intact pH
11	35	female	47	6.3	7.0
12	38	man	17	6.5	7.3
13	43	man	48	6.5	7.4
14	46	man	46	6.5	7.4
15	48	man	37	6.5	7.1
16	52	man	46	6.4	7.3
17	54	man	36	6.3	7.1
18	56	female	27	6.4	7.3
19	56	man	47	6.6	7.3
20	57	female	46	6.5	7.2

carious attack might be related to different types of organisms which are capable of acidogenesis at a low pH. Most oral bacteria only grow if the pH is within a narrow range, usually between pH 6 and 8, but some oral bacteria are acidic and will grow at a significantly lower pH (Hamada & Slade 1980; Larsen & Pearce, 1997). The mutans streptococci can produce large quantities of acid even at a relatively low pH (Harper & Loesche, 1984; de Soet, Nyvad & Kikian, 2000). Harper & Loesche (1984) postulated that pH 5.5 falls above a threshold for acidogenic stimulation of mutans streptococci. Young & Massler (1963) indicated that an arrested dentinal lesion was more resistant to proteolytic enzyme attack than active dentinal lesions. Further studies on active and arrested carious lesions using extracted human teeth are required in order to investigate the acidogenic plaque bacteria and caries activity.

Following staining with a methyl red indicator of sectioned teeth, MacGregor (1962) indicated that a low pH area was almost always observed around the periphery of the softening and invasion of excavated dentinal cavities. Sarnat & Massler (1965) suggested that remineralization of the surface layer by salivary ions and hypermineralization with obliteration of tubules by minerals derived from the pulp were most evident in arrested lesions. In this study, the lowest pH point was always detected on the inner area from the periphery of pH imaging of carious lesion characterization. Moreover, the pH level gradually rose from the lowest pH level up to the level of the intact dentin. There is apparently a balance between the destructive process and the response of the tooth (Miller & Massler, 1962). The lesion may never become completely arrested or it may become reactivated.

The color of carious dentin has generally been used as a one of clinical criterion for carious dentin diagnosis. Fusayama (1988) reported that a staining technique using a basic fuchsin solution aided in the differentiation of the two layers of carious dentin. The outer carious dentin is irreversibly denaturated, infected and not remineralizable (Fusayama, 1979). The inner carious dentin is reversibly denatured, not infected, remineralizable and should be preserved. Although caries detector staining was not clear in arrested caries dentin, in this study, the outline of the visually inspected comparison between the darkly stained and pH-imaged area within the caries lesion resembled each other. In its present form, the pH-imaging sensor is too large for clinical application, but a smaller version could enable *in vivo* pH-imaging characterization of caries lesion. This pH analysis could be used on these sites of clinical uncertainty as diagnostic adjunct for determining an arrested carious lesion.

CONCLUSIONS

Detection of a lesion and estimating its caries activity are important parts of the diagnostic process because if the lesion is thought to be active, it is often instrumental in determining the choice of intervention. In this study, surface analysis of sections of carious dentin using a pH-imaging microscope could distinguish between active and arrested carious lesions.

Acknowledgements

The authors thank Dr Michael F Burrow, Dr Richard M Foxton and Dr Yuichi Seki for their helpful advice in preparing the manuscript. The authors gratefully acknowledge personnel at the Ohno Dental Clinic for their cooperation.

(Received 10 September 2001)

References

Barber D & Massler M (1964) Permeability of active and arrested carious lesions to dye and radioisotopes *Journal of Dentistry for Children* **31(1)** 26-33.

Brown WE, Patel PR & Chow LC (1975) Formation of Ca HPO_4 $2H_2O$ from enamel mineral and its relationship to caries mechanism *Journal of Dental Research* **54(3)** 475-481.

de Soet JJ, Nyvad B & Kikian M (2000) Strain-related acid production by oral streptococci *Caries Research* **34(6)** 486-490.

Fusayama T (1979) Two layers of carious dentin; diagnosis and treatment *Operative Dentistry* **4(2)** 63-70.

Fusayama T (1988) Clinical guide for removing caries using a caries-detecting solution *Quintessence International* **19(6)** 397-401.

Hafeman DG, Parce JW & McConnell HM (1988) Light-addressable potentiometric sensor for biochemical systems *Science* **240(4856)** 1182-1185.

Hamada S & Slade HD (1980) Biology, immunology, and cariogenicity of *Streptococcus mutans Microbiological Reviews* **44(2)** 331-384.

Harper DS & Loesche WJ (1984) Growth and acid tolerance of human dental plaque bacteria *Archives of Oral Biology* **29(10)** 843-848.

Igarashi K, Kamiyama K & Yamada T (1981) Measurement of pH in human dental plaque *in vivo* with an ion-sensitive transistor electrode *Archives of Oral Biology* **26(3)** 203-207.

Kitasako Y, Nikaido T, Tagami J, Ikeda K, Mitsunari K & Nomura S (2000) Surface analysis of carious dentin using a pH imaging microscope based on a semi-conductor silicon sensor *Bunseki Kagaku* **49(5)** 325-327.

Larsen MJ & Pearce EIF (1997) A computer program for correlating dental plaque pH values, cH^+, plaque titration, critical pH, resting pH and the solubility of enamel apatite *Archives of Oral Biology* **42(7)** 475-480.

Lynch E & Beighton D (1994) A comparison of primary root caries lesions classified according to color *Caries Research* **28(4)** 233-239.

MacGregor AB (1962) The extent and distribution of acid in carious dentin *Proceedings of the Royal Society of Medicine* **55** 1063-1066.

Massler M (1945) Teen-age caries *Journal of Dentistry for Children* **12(1)** 57-64.

Mechanic GL (1971) The intermolecular cross-link precursors in collagens as related to function. Identification of -hydroxy-amino adipic semialdehyde in tendon collagen *Israel Journal of Medical Science* **7(3)** 458-462.

Miller WA & Massler M (1962) Permeability and staining of active and arrested lesions in dentin *British Dental Journal* **112(5)** 187-197.

Nomura S, Nakao M, Nakanishi T, Takamatsu S & Tomita K (1997) Real-time imaging of microscopic pH distribution with a two-dimensional pH imaging apparatus *Analytical Chemistry* **69(5)** 977-981.

Nomura S, Mitsunari K, Nakao M, Kohno Y & Matsuki R (2000) Estimation of plant leaf response to acid solutions using a pH-imaging microscope *GIT Imaging & Microscopy* **2** 59-61.

Ogawa K, Yamashita Y, Ichijo T & Fusayama T (1983) The ultrastructure and hardness of the transparent layer of human carious dentin *Journal of Dental Research* **62(1)** 7-10.

Parikh SR, Massler M & Bahn A (1963) Micro-organism in active and arrested carious lesions *New York State Dental Journal* **29(8)** 347-355.

Sanaone C, Van Houte J, Joshipura K, Kent R & Margolis HC (1993) The association of mutans streptococci and non-mutans streptococci capable of acidogenesis at a low pH with dental caries on enamel and root surfaces *Journal of Dental Research* **72(2)** 508-516.

Sarnat H & Massler M (1965) Microstructure of active and arrested dentinal caries *Journal of Dental Research* **44(6)** 1389-1401.

Siegel S & Castellan NJ (1988) *Non-parametric Statistics for the Behavioral Science*, 2nd edition New York McGraw-Hill.

Stephan RM & Miller BF (1943) A quantitative method for evaluating physical and chemical agents which modify production of acids in bacterial plaques on human teeth *Journal of Dental Research* **22(1)** 45-51.

Stephan RM (1944) Intraoral hydrogen ion concentration associated with dental caries activity *Journal of Dental Research* **23(4)** 257-266.

Van Houte J, Sansone C, Joshipura K & Kent R (1991) *In vitro* acidogenic potential and mutans streptococci of human smooth-surface plaque associated with initial caries lesions and sound enamel *Journal of Dental Researc*h **70(12)** 1497-1502.

Young MA & Massler M (1963) Some physical and chemical characteristics of carious dentin *British Dental Journal* **115(10)** 406-412.

©Operative Dentistry, 2002, **27**, 360-366

A Scanning Electron Microscopic Study of Different Caries Removal Techniques on Human Dentin

AR Yazici • G Özgünaltay • B Dayangaç

Clinical Relevance

SEM examination of dentin surface after different caries removal techniques provide new insight into the mechanisms of bonding resins to dentin.

SUMMARY

Scanning electron microscopy (SEM) evaluated the effect of different caries removal techniques on human dentin topography. Thirty-six extracted human carious mandibular molars were randomly assigned to six groups according to caries removal technique. Carious tissue was removed by hand excavation, bur excavation, air-abrasion, laser ablation, chemomechanical methods and sono-abrasion. The remaining dentin surfaces were replicated and gold-coated. The surfaces were examined using SEM and distinct differences in appearance were observed among specimens treated with different caries removal techniques. While hand-excavated, bur-excavated and air-abraded carious dentin surfaces were covered with a residual smear layer, sono-abrasion with patent dentinal tubules completely removed the smear layer. A few patent orifices of dentinal tubules were observed in dentin subjected to laser ablation and chemo-mechanical caries removal.

*A Rüya Yazici, DDS, PhD, instructor, Hacettepe University

Gül Özgünaltay, DDS, PhD, associate professor, Hacettepe University

Berrin Dayangaç, DDS, PhD, professor, Hacettepe University

*Reprint request: Faculty of Dentistry, Dept. of Conservative Dentistry, 06100, Sihhiye, Ankara, Turkey; e-mail: muharrem.yazici@isbank.net.tr

INTRODUCTION

Conventional cavity preparation and caries removal are based on Black's principle of extension for prevention. This principle requires removing healthy tooth structure, which is very destructive and leads to excessive tissue loss. In recent years, conservative cavity preparation has gained popularity with the introduction of adhesive resin bonding systems. Current practice keeps the size of cavities as small as possible. Conservative cavity preparation, which includes handpieces and burs, leads to undesirable removal of tooth structure. Due to this excessive loss of sound tissue, efforts have focused on new techniques, such as sono-abrasion, air-abrasion, laser and Carisolv gel for caries removal.

Sono-abrasion is a special system solution for minimally invasive treatment (Liebenberg, 1998; Hugo & Stassinakis, 1998). The Sonicsys (KaVo, Kaltenbach & Voight and Vivadent, Schaan, Liechtenstein) preparation tips facilitate a preparation with ideal angles and precise margins. Instead of the rotary action of standard instruments, the tips merely oscillate. They are safe-sided so that no damage to the adjacent tooth will occur during preparation.

Another method of caries removal is air-abrasion, or kinetic cavity preparation (Goldstein & Parkins, 1994; Horiguchi & others, 1998). The technique's basic principle involves using the kinetic energy of a well-defined, sharply focused stream of tiny aluminum oxide (Al_2O_3) particles propelled by high-velocity air pressure (Black, 1945, 1950, 1955; Laurell & Hess, 1995). The abrasive particles that strike the tooth remove small amounts of tooth structure.

For more than 30 years, lasers have been a subject of investigation for possible hard tissue applications. Today, they are considered suitable for caries removal and tooth preparation (Myers & Myers, 1985; White & others, 1991; Bassi, Chawla & Patel, 1994; Keller & Hibst, 1997). As carious dentin is darker than sound dentin, the energy levels of the laser can be adjusted so that an optimal amount of light is absorbed, sufficient to remove only the carious dentin, leaving the sound dentin intact.

A new chemo-mechanical system for removing caries has recently been introduced as an alternative to the mechanical excavation of carious dentin (Beeley, Yip & Stevenson, 2000; Ericson & others, 1999). This caries removal system consists of a red gel and a transparent liquid. The components of the red gel are 0.1 M amino acids (glutamic acid, leucine and lysine), NaCl, NaOH, erythrosine and purified water. The transparent liquid contains sodium hypochlorite (NaOCl-0.5% w/v). This gel was developed to facilitate removal of carious dentin by softening, after which it can be scraped away with specially designed hand instruments.

The surface of cut dentin after caries removal forms the basis for establishing a bond between tooth structure and restoration. The smear layer, which is the organic debris that remains on the dentin surface after preparation of the dentin, may be regarded as a surface contaminant, limiting interaction with the subsurface dentin and its organic and organic bonding areas, thus reducing bond strength (Eick & others, 1970; Ehudin & Thompson, 1994). The smear layer blocks the dentinal tubules and acts as a "diffusion barrier." This barrier is thought to protect the pulp by decreasing the permeability of dentin (Pashley, Michelich & Kehl, 1981). However, one of the current practices for obtaining maximum bond strength to dentin creates a hybrid zone in which a primer and adhesive can better penetrate the surface when the smear layer has been removed. Using an acidic conditioner prior to applying resin is necessary to remove the smear layer.

As the morphology of dentin is one of the main factors affecting the success of dentin bonding, the authors investigated the influence of current clinical caries removal techniques on dentin surface topography.

METHODS AND MATERIALS

Sixty extracted human carious mandibular molars (from patients 20-35 years of age) were stored in 1% chloramin T solution at 4ºC for a maximum of two weeks. After scaling the residual tissue, the teeth were cleaned with a pumice-water slurry and examined under a dissection microscope for cracks and fissures. Although all teeth had approximal caries visible to the naked eye, Diagnodent (KaVo Dental, Biberach, Germany), a new laser fluorescence device was used for standardization. The laser device was applied directly to the approximal surfaces of the teeth using the flat "B" probe and the maximum reading was recorded. While 24 teeth with a peak surface reading below 30, which indicates enamel caries, were excluded from the study, 36 teeth with values equal to or greater than 30 (30-40), which indicates caries involving dentin, were selected for the study (Lussi & others, 2001). Teeth were randomly assigned to six groups according to caries removal technique. An independent examiner judged whether the cavity was caries-free according to certain criteria (Kidd, Joyston-Bechal & Beighton, 1993; Kidd, Ricketts & Beighton,1996): removal of all soft and stained dentin, stopping at stained or not stained but hard to sharp explorer probing, the absence of sticking in the dentin or of a "tug-back" sensation.

Technique I (Hand excavation): Carious tissue was excavated from the tooth with a spoon-shaped excavator (A-145, Maillefer Instruments, Dentsply, CH-1338, Ballaigues, Switzerland).

Technique II (Bur excavation): Carious tissue was removed with a size 4 (ISO No 310204014) round steel bur (Hager & Meisinger GmbHD-40018, Düsseldorf, Germany) in a slow-speed handpiece under water spray. The maximum cutting diameter of the bur was 1.4 mm. A new bur was used for each tooth.

Technique III (Air-abrasion): Caries removal was accomplished with a PrepStar air-abrasion unit (Danville Engineering, San Ramon, CA 94583, USA) using a 50 µm aluminum oxide particle stream at 120 psi pressure. The treatment took place at a distance of approximately 3 mm from the carious surface.

Technique IV (Laser ablation): Caries was removed with a normal pulsed Nd:YAG laser (MediLas 4060, Medizintechnik GmbH, München, Germany) with a wavelength of 1.06 µm at 1.5W, and a repetition rate of 2 Hz. The laser was delivered via a quartz optical fiber held 3 mm from the carious tissue and used in a non-contact mode in a back and forth motion.

Technique V (Carisolv gel excavation): Carisolv gel (MediTeam Dental AB, Sävedalen, Sweden) was applied on carious dentin for 30 seconds. The softened dentin was removed with a specially designed excavator (Carisolv instrument 2, Star3/Multistar HS nr 901841, Switzerland). The procedure was repeated until the gel was no longer cloudy.

Technique VI (Sono-abrasion): A soniflex airscaler handpiece (Sonicsys Micro, KaVo, Kaltenbach &Voight and Vivadent, Schaan, Liechtenstein) with a diamond-coated tip oscillating in the sonic region (<6.5kHz) was used to remove carious tissue. The hemispherically-shaped tip (diameter: 1.5 mm) was coated on one side with a 40 µm grit diamond.

The same investigator carried out all caries removal procedures. After excavation was achieved using different methods, the teeth were longitudinally sectioned into two halves through the middle of the cavities with a diamond saw. They were then washed vigorously and air dried gently. The sections were replicated immediately by making a polyvinylsiloxane impression (Panasil Contact Plus, Kettenbach Dental, Eschenburg, Germany) of the sectioned surface. The samples were removed from the set impressions, into which epoxy resin (Stycast; Grace, Westerlo, Belgium) cured at 37ºC for 48 hours was poured. All replicas were coated with gold of a thickness of 250-300Aº under vacuum in a Hummer X sputter coater (Anatech Ltd, Alexandria,VA 22150, USA). All replicas were examined using a scanning electron microscope (JEOL JSM-6400 Tokyo, Japan) operating at 20kv. Images were recorded on Ilford FP4, 125 ASA black and white film (Ilford Ltd Mobberly, Cheshire, England, UK) via a camera (JEOL UHR Camera, 90439, Tokyo, Japan) linked to the scanning electron microscope. Photographs were taken at x1000 magnification.

RESULTS

SEM showed that the appearance of dentin and the smear layer morphology varied distinctly in different caries removal techniques.

Technique I (Hand excavation): Figure 1 shows a dentin surface from which carious dentin was removed by hand excavator. The surface was irregular with grooves. There was no evidence of the tubular structure of dentin. The smeared debris did not form a continuous layer but was present in the form of localized islands with discontinuities. The dentin surface also had areas of microchipping and scratching.

Technique II (Bur excavation): Figure 2 shows a dentin surface from which carious dentin was removed by bur excavation. Note the typical appearance of a homogeneous smear layer created with the round bur in which cutting anomalies and smear debris cover the tissue. Uniform roughness with no opening of the dentinal tubules is visible.

Technique III (Air-abrasion): Figure 3 shows the morphological characteristics of dentin surfaces following air-abrasion. The dentin exhibited a porous, sponge-like appearance. Most probably, the impact of aluminum oxide powder particles, highly accelerated by compressed air, caused the very irregular surface morphology. Remnants of alumina powders were identified as white particles. Tubular openings were occluded by surface debris.

Technique IV (Laser ablation): Figure 4 shows the SEM view of dentin surfaces after laser ablation. Dentin debris occluded most of the tubule openings with an irregular, roughened texture.

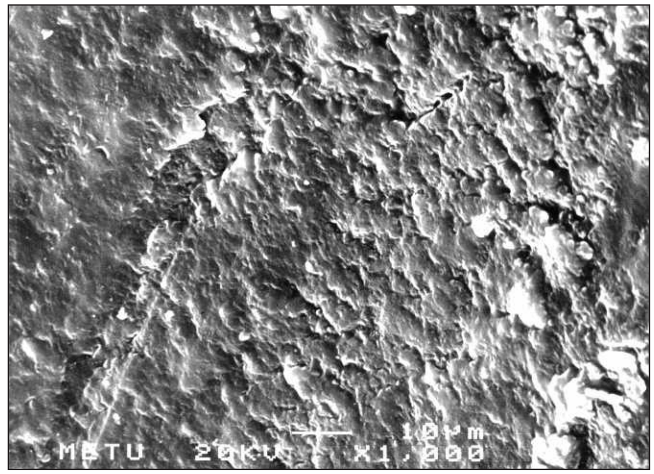


Figure 1. *Carious dentin surface prepared with hand excavator. The smear layer is discontinuous with islands of chipping (x1000).*

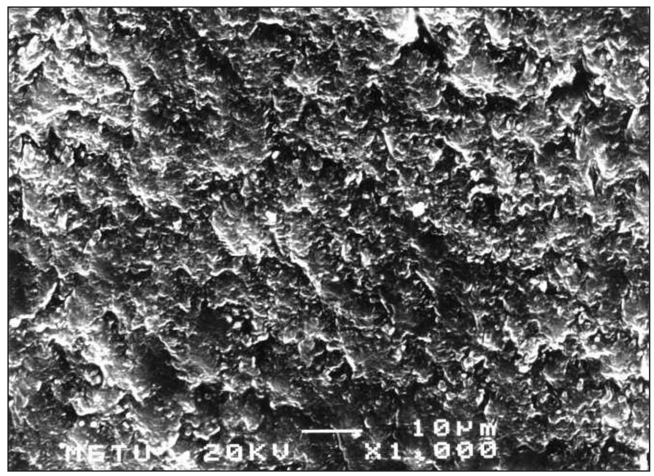


Figure 2. *Carious dentin surface prepared with bur. A smooth and uniform smear layer is evident (x1000).*

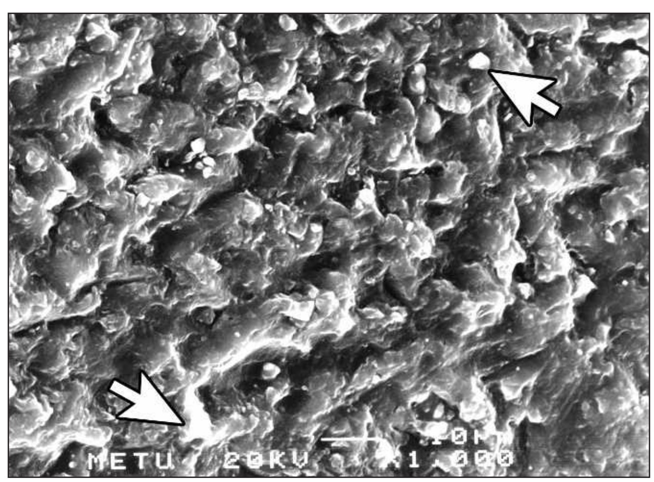


Figure 3. *Irregular smear layer formed after air-abrasion of carious dentin. Note the sponge-like appearance of the prepared surface. Remnants of alumina particles (arrows) can be seen (x1000).*

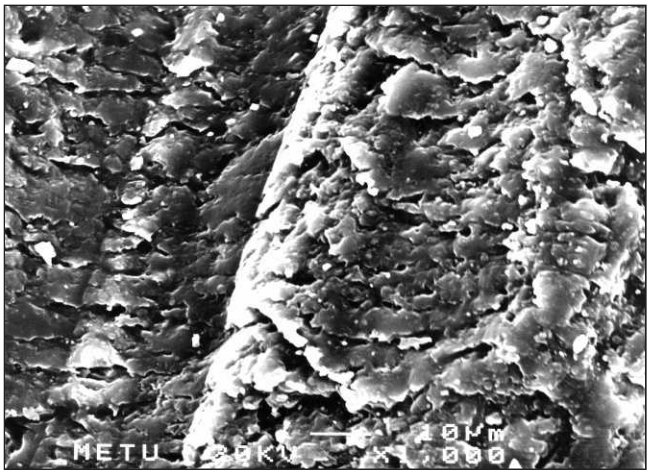


Figure 4. *Laser irradiated carious dentin. An irregular and globular formation of the smear layer with partly occluded dentin tubules (x1000).*

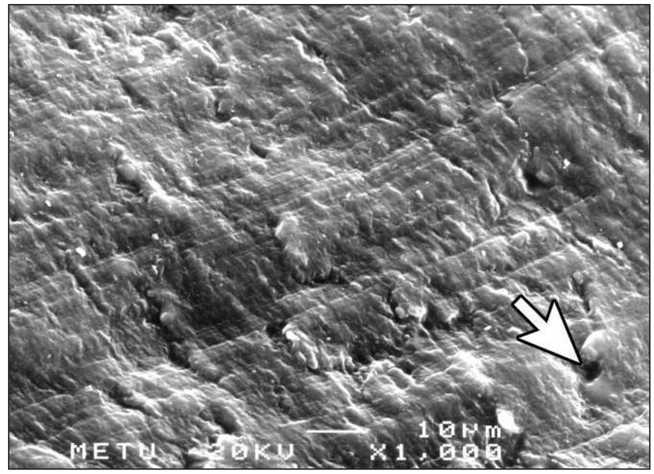


Figure 5. *Carious dentin surface treated with Carisolv. Note smooth and homogenous smear layer. Despite traces of instrumentation, the area reveals a smooth surface. Partly occluded dentinal tubules are visible. One orifice of the dentinal tubules (arrow) seen at 4 o'clock (x1000).*

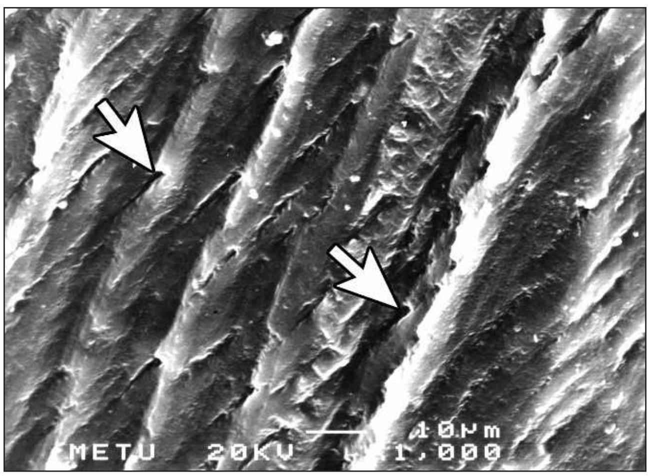


Figure 6. *Carious dentin treated with sono-abrasion. Traces of instrumentation is rather accentuated compared to other techniques. Orifices of the dentinal tubules (arrows) are evident (x1000).*

Technique V (Carisolv gel excavation): The surface of dentin treated with Carisolv was observed to be smoother than mechanically cut dentin (Figure 5). Some striations were made by Carisolv hand instruments and a packed smear layer was created by the gel. Partially occluded dentinal tubules were also seen. One or two tubule openings were imaged.

Technique VI (Sono-abrasion): There was no evidence of a smear layer on the dentin surface on which the caries removal was performed with Sonicsys micro. An undulating pattern was observed (Figure 6). Fine grooves running parallel to the undulations were seen. An irregular surface showing the orifices of the dentinal tubules was clearly visible.

DISCUSSION

This study examined dentin surfaces after different caries removal techniques. The scanning electron microscope was used since it is well suited to identifying and characterizing the changes produced during cutting, abrading and ablating dental tissues. However, analysis of tooth substances by scanning electron microscope has some major disadvantages (Taylor & Lynch, 1993). Desiccation of tissue during preparation for the high vacuum necessary for the scanning electron microscope may lead to some cracking. It is likely that artefactual gaps and distortion of the specimen will occur, especially in dentin with a high water content. Therefore, replicas of the prepared samples were obtained for SEM analysis. The use of polyvinylsiloxane impression materials is widely recommended due to its high dimensional stability (Pameijer, 1979).

Dentin surface preparation with a hand instrument (excavator) produced severe smearing of the prepared surface. Boyde, Knight & Jones (1972) made a similar observation. Debris, irregular in shape and non-uniform in size and distribution, can easily be seen on the dentin surface.

Dentin surfaces undergoing bur excavation had a layer of cutting debris. This typical observation of a smear layer is supported by other investigators who have reported that dental instruments leave a smear layer of organic and hydroxyapatite particles that cover both enamel and dentin (el-Housseiny & Jamjoum, 2000). Brännström & Johnson (1974) showed that smear layers were common on dentin surfaces following the use of burs.

The alumina air-abraded dentin surface appeared very rough and pitted. The authors also observed that air-abrasion unit created a smear layer on the surface and sealed the tubules. These observations were confirmed by a quantitative SEM study that showed the openings of the dentin tubules to be blocked by debris (Laurell & Hess, 1995; Manhart & others, 1999; Los & Barkmeier, 1994; Nikaido & others, 1996). Contrary to other investigators (Laurell & Hess, 1995; Manhart & others, 1999), the authors of this study observed aluminum oxide particles on air-abraded dentin surfaces. This may have occurred as a result of inefficient cleaning of the abraded surfaces with water spray. The dentin surface observed after removal of caries by air-abrasion could account for a mechanical retention of the resin due to increased surface roughness. A number of studies suggest that air-abrasion increases the surface roughness of dentin and enamel (Laurell, Lord & Beck, 1993; Keen, von Fraunhofer & Parkins, 1994; Moritz & others, 1996).

Nd:YAG laser with a 1.06 µm wavelength is highly absorbed by pigmented tissue and absorbed by dental hard tissue (Hecht, 1992). Since only pigmented surfaces such as carious lesions are vaporized by laser emission, this treatment keeps adjacent tooth structure safe. Exposure to the laser system during removal of the carious tissue resulted in a surface characterized by crazings, undercuts and irregularities. Various investigators have reported similar results when evaluating the effects of lasers on dentin (Cooper & others, 1988). Although other studies have looked at the effects of laser irradiation on enamel and dentin, there are few detailed descriptions concerning the effects of lasers on dentin surfaces after caries removal. Intertubular dentin contains more organic matrix than peritubular dentin, and intertubular dentin is selectively dissolved by the vaporization effect of the laser, and peritubular dentin shows localized melting and sealing of dentin tubules (Neev & others, 1991; Arima & Matsumoto, 1993). This may be why a limited number of partially occluded dentin tubules were observed, suggesting that smear is still present after laser irradiation of the dentin surface. This agrees with the study by Stabholz & others (1993).

A number of minute cracks on dentin surfaces were seen in specimens prepared with Carisolv. Banerjee, Kidd & Watson (2000) have stated that these microcracks might be due to the hydrophilic nature of the gel, which causes dehydration of the dentin surface. Although most reports indicate that Carisolv removes the smear layer and exposes dentin tubules (Banerjee, Watson & Kidd, 1999), in this study, the Carisolv treatment did not totally remove the smear layer. The authors observed a layer of cutting debris and fine marks left by hand instruments. This smear layer might occur due to high force application during mechanical excavation. Hosoya & others (2001) observed partially opened dentinal tubules and remnants of smear layer covering the dentin surface following the Carisolv treatment. However, other investigators have found that Carisolv fails to remove the smear layer and no patent dentin tubules are visible (Cederlund, Lindskog & Blomlöf, 1999a). Their study was conducted on non-carious dentin surfaces. In another study that agrees with the current findings, Cederlund, Lindskog & Blomlöf (1999b) observed a wave-like smear layer covered both the enamel and dentin surfaces and some apertures of the dentin tubules blocked by debris in limited areas only. Contrary to this study's observations, Banerjee & others (2000) reported that a minimal smear layer occurred and the tubule orifices appeared patent after chemo-mechanical caries removal with Carisolv. In view of these diverse results, it appears that this chemo-mechanical caries removal system is technique sensitive and shows operator variability.

Dentin tubules were clearly seen in sono-abraded dentin surfaces in this study, contrary to the assertion made by Banerjee & others (2000), who also reported dentin smearing on a sono-abraded surface. The authors of the current study observed no smear layer in their sono-abraded specimens.

SEM analysis showed the presence of open dentinal tubules and the loss of smear layer following the sono-abrasion technique, alone. However, if total acid etching of the cavity is to be performed prior to applying an adhesive resin, then the pulpal consequences of acid etching of the dentin with previously opened tubules should be considered (Pameijer & Stanley, 1998; Tasman & others, 2000). Loss of the smear layer also increases the surface area available for the diffusion of molecules and the penetration of bacteria into pulp (Olgart, Brännström & Johnson, 1974; Michelich, Schuster & Pashley, 1980). In this respect, the effectiveness of this technique is questionable with regard to the harmful effects of acid etching on dentin (Gwinnett & Tay, 1998; Cehreli & others, 2000). In preparing dentin surfaces for bonding, the viability of this tissue must be taken into account. Clearly, more research is needed regarding the appropriateness of the acid etching of dentin without smear layer and with opened tubules. In addition, further study is needed regarding the long-term maintenance of bond strengths to dentin after different caries removal techniques *in vivo*.

CONCLUSIONS

SEM revealed distinct differences in the surface texture and morphology of the specimens between hand excavation, bur excavation, air-abrasion, laser ablation, chemo-mechanical and sono-abrasion caries removal techniques. Only the sono-abrasion technique removed caries dentin without the formation of a smear layer and with patent dentinal tubules.

Acknowledgements

The authors acknowledge Cengiz Tan for technical assistance with SEM. The authors also gratefully acknowledge MediTeam Dental AB, Sweden for supplying Carisolv and excavation instruments. In addition, special thanks go to Dan Ericson for his comments and Christina Kultje for her cooperation.

(Received 10 September 2001)

References

Arima M & Matsumoto K (1993) Effects of ArF: Excimer laser irradiation on human enamel and dentin *Lasers in Surgery and Medicine* **13(1)** 97-105.

Banerjee A, Kidd EA & Watson TF (2000) Scanning electron microscopic observations of human dentine after mechanical caries excavation *Journal of Dentistry* **28(3)** 179-186.

Banerjee A, Watson TF & Kidd EAM (1999) Carious dentine excavation using Carisolv gel: A quantitative, autofluorescence assessment using scanning microscopy *Caries Research* **33** 313.

Bassi G, Chawla S & Patel M (1994) The Nd:YAG laser in caries removal *British Dental Journal* **177(7)** 248-250.

Beeley JA, Yip HK & Stevenson AG (2000) Chemochemical caries removal: A review of the techniques and latest developments *British Dental Journal* **188(8)** 427-430.

Black RB (1945) Technic for non-mechanical preparation of cavities and prophylaxis *Journal of the American Dental Association* **32(15)** 955-965.

Black RB (1950) Airbrasive: Some fundamentals *Journal of the American Dental Association* **41(6)** 701-710.

Black RB (1955) Application and revaluation of air abrasive technic *Journal of the American Dental Association* **50(4)** 408-414.

Boyde A, Knight PJ & Jones SJ (1972) Further scanning electron microscope studies of the preparation of Class II cavities *British Dental Journal* **132(11)** 447-457.

Brännström M & Johnson G (1974) Effects of various conditioners and cleaning agents on prepared dentin surfaces: A scanning electron microscopic investigation *Journal of Prosthetic Dentistry* **31(4)** 422-430.

Cederlund A, Lindskog S & Blomlöf J (1999a) Effect of a chemomechanical caries removal system (Carisolv) on dentin topography of non-carious dentin *Acta Odontologica Scandinavica* **57(4)** 185-189.

Cederlund A, Lindskog S & Blomlöf J (1999b) Efficacy of Carisolv-assisted caries excavation *International Journal of Periodontics and Restorative Dentistry* **19(5)** 464-469.

Cehreli ZC, Turgut M, Olmez S, Dagdeviren A & Atilla P (2000) Short-term human primary pulpal response after direct pulp capping with fourth-generation dentin adhesives *Journal of Clinical Pediatric Dentistry* **25(1)** 65-71.

Cooper LF, Myers ML, Nelson DG & Mowery AS (1988) Shear strength of composite bonded to laser-pretreated dentin *Journal of Prosthetic Dentistry* **60(1)** 45-9.

Ehudin DZ & Thompson VP (1994) Tensile bond strength of dental adhesives bonded to simulated caries-exposed dentin *Journal of Prosthetic Dentistry* **71(2)** 165-173.

Eick JD, Wilko RA, Anderson CH & Sorensen SE (1970) Scanning electron microscopy of cut tooth surfaces and identification of debris by use of the electron microprobe *Journal of Dental Research* **49(6)** 1359-1368.

el-Housseiny AA & Jamjoum H (2000) The effect of caries detector dyes and a cavity cleansing agent on composite resin bonding to enamel and dentin *Journal of Clinical Pediatric Dentistry* **25(1)** 57-63.

Ericson D, Zimmerman M, Raber H, Götrick B, Bornstein R & Thorell J (1999) Clinical evaluation of efficacy and safety of a new method for chemo-mechanical removal of caries *Caries Research* **33(3)** 171-177.

Goldstein RE & Parkins FM (1994) Air-abrasive technology: Its new role in restorative dentistry *Journal of the American Dental Association* **125(5)** *551-557.*

Gwinnett AJ & Tay F (1998) Early and intermediate time response of the dental pulp to an acid etch technique *in vivo American Journal of Dentistry* **11** S35-44.

Hecht J (1992) Nd:YAG lasers prove versatile over three decades *Laser Focus World* **4** 126-132.

Horiguchi S, Yamada T, Inokoshi S & Tagami J (1998) Selective caries removal with air abrasion *Operative Dentistry* **23(5)** 236-243.

Hosoya Y, Kawashita Y, Marshall GW Jr & Goto G (2001) Influence of Carisolv for resin adhesion to sound human primary dentin and young permanent dentin *Journal of Dentistry* **29(3)** 163-171.

Keen DS, von Fraunhofer JA & Parkins FM (1994) Air abrasive "etching": Composite bond strengths *Journal of Dental Research* **73** Abstract #238 p 131.

Keller U & Hibst R (1997) Effects of Er:YAG laser in caries treatment: A clinical pilot study *Lasers in Surgery and Medicine* **20(1)** 32-38.

Kidd EA, Joyston-Bechal S & Beighton D (1993) Microbiological validation of assessments of caries activity during cavity preparation *Caries Research* **27(5)** 402-408.

Kidd EA, Ricketts DN & Beighton D (1996) Criteria for caries removal at the enamel-dentine junction: A clinical and microbiological study *British Dental Journal* **180(8)** 287-291.

Laurell H, Lord W & Beck M (1993) Kinetic cavity preparation effects on bonding to enamel and dentin *Journal of Dental Research* **72** Abstract #1437 p 283.

Laurell KA & Hess JA (1995) Scanning electron micrographic effects of air-abrasion cavity preparation on human enamel and dentin *Quintessence International* **26(2)** 139-144.

Los SA & Barkmeier WW (1994) Effects of dentin air abrasion with aluminum oxide and hydroxyapatite on adhesive bond strength *Operative Dentistry* **19(5)** 169-175.

Lussi A, Megert B, Longbottom C, Reich E & Francescut P (2001) Clinical performance of a laser fluorescence device for detection of occlusal caries lesions *European Journal of Oral Science* **109(1)** 14-19.

Manhart J, Mehl A, Schroeter R, Obster B & Hickel R (1999) Bond strength of composite to dentin treated by air abrasion *Operative Dentistry* **24(4)** 223-232.

Michelich V, Schuster GS & Pashley DH (1980) Bacterial penetration of human dentin *in vitro Journal of Dental Research* **59(8)** 1398-1403.

Moritz A, Gutknecht N, Schoop U, Goharkhay K, Wernisch J & Sperr W (1996) Alternatives in enamel conditioning: A comparison of conventional and innovative methods *Journal of Clinical Laser Medicine and Surgery* **14(3)** 133-136.

Myers TD & Myers WD (1985) The use of a laser for debridement of incipient caries *Journal of Prosthetic Dentistry* **53(6)** 776-779.

Neev J, Liaw LH, Raney DV, Fujishige JT, Ho PD & Berns MW (1991) Selectivity, efficiency, and surface characteristics of hard dental tissues ablated with ArF-pulsed excimer lasers *Lasers in Surgery and Medicine* **11(6)** 499-510.

Nikaido T, Kataumi M, Burrow MF, Inokoshi S, Yamada T & Takatsu T (1996) Bond strengths of resin to enamel and dentin treated with low-pressure air abrasion *Operative Dentistry* **21(5)** 218-224.

Olgart L, Brännström M & Johnson G (1974) Invasion of bacteria into dentinal tubules *Acta Odontologica Scandinavica* **32(1)** 61.

Pameijer CH (1979) Replication techniques with new dental impression materials in combination with different negative impression materials *Scanning Electron Microscopy* **2** 571-574.

Pameijer CH & Stanley HR (1998) The disastrous effects of the "total etch" technique in vital pulp capping in primates *American Journal of Dentistry* **11** S45-54.

Pashley DH, Michelich V & Kehl T (1981) Dentin permeability: Effects of smear layer removal *Journal of Prosthetic Dentistry* **46(5)** 531-537.

Stabholz A, Neev J, Liaw LH, Stabholz A, Khayat A & Torabinejad M (1993) Sealing of human dentinal tubules by XeCl 308-nm excimer laser *Journal of Endodontics* **19(6)** 267-271.

Tasman F, Cehreli ZC, Onur MA & Gumrukcuoglu A (2000) Effect of different single-bottle dentin adhesives on vascular responses in rat carotid artery *American Journal of Dentistry* **13(6)** 337-339.

Taylor MJ & Lynch E (1993) Marginal adaptation *Journal of Dentistry* **21(5)** 265-273.

White JM, Goodis HE, Coloma AJ & Marshall GW (1991) Removal of caries in dentin using a Nd:YAG laser *Journal of Dental Research* **70(Special Issue)** Abstract #1820 pg 412.

©Operative Dentistry, 2002, **27**, 367-372

Comparative Analysis of Pulpal Circulatory Reaction to an Acetone-Containing and an Acetone-Free Bonding Agent as Measured by Vitalmicroscopy

I Iványi • ÁE Balogh • Á Fazekas
L Rosivall • I Nyárasdy

Clinical Relevance

Resin composite bonding agents applied onto a thin layer of pulpal dentin have acute and reversible vasodilating effect independent of acetone content.

SUMMARY

Despite great progress in the production of new dental polymers, application of these products is still controversial. The unlined utilization of cytotoxic adhesive materials on pulpal dentin can adversely influence the pulp, leading to alterations in local microcirculation that can be an early sign of pathological changes. In a previous study by the authors, the effect of an acetone-free bondmaterial was examined on the vascular diameter of pulpal vessels by means of vitalmicroscopy. In this study, experiments comparing experimental data provided by an acetone-containing bondmaterial to these earlier findings with acetone-free ones have been performed. Thirty male Sprague-Dawley rats (weighing 333±9 g) were used for this investigation. The first lower incisor was prepared for vitalmicroscopy. Changes in vessel diameter were recorded prior to and 5, 15, 30 and 60 minutes after the investigated materials (Scotchbond Multi-Purpose Dental Adhesive System or Prime & Bond 2.1) were administered on dentin as recommended by the manufacturer. In control rats (saline administration), the vessel diameter was stable during the experiment. In the presence of acetone-free bondmaterial (Scotchbond), the vessel diameter was increased during the experimental period in relation to the baseline (12.15±2.85%; 16.36±2.39%; 14.16±3.48%; 12.12±3.72%). In the presence of acetone-containing bondmaterial (Prime & Bond 2.1), a similar result was observed (10.56±2.27%; 16.13±2.94%; 17.88±2.54%; 14.54±3.16%). The differences between the control values and those registered with test groups were significant ($p<0.05$; ANOVA). There was no significant difference among the test groups. The results of this study suggest that dental bond materials applied on a very thin layer of dentin may affect the blood supply to the dental pulp.

*I Iványi, DMD, assistant professor, Semmelweis University

ÁE Balogh, DMD, assistant professor, Semmelweis University

Á Fazekas, DMD, PhD, DSc, professor, Semmelweis University

L Rosivall, MD, PhD, DSc, Med, professor, Semmelweis University, Faculty of Medicine, Department of Pathophysiology

I Nyárasdy, DMD, PhD, associate professor, Semmelweis University

*Reprint request: Semmelweis University, Faculty of Dentistry, Department of Conservative Dentistry, 1088 Budapest, Mikszáth K tér, Hungary; e-mail: ivanyi@konfog.sote.hu

However, no stasis or prestasis has been detected, indicating a possible reversible effect. The authors could not show any statistical difference between the vasodilatation caused by the acetone-containing and the acetone-free bond material.

INTRODUCTION

The increasing demand for esthetic treatments in dentistry has led to the widespread use of resin and resin-monomers for bonding tooth-colored restorations to dentin. Since currently available resin-based materials still show various inferior features, intensive research concerning them continues. In terms of pulpal toxicity, in recent years the key role of bacterial leakage at the restoration-tooth interface has been emphasized (Brännström, Vojinovic & Nordenvall, 1979; Bergenholtz, 2000). However, many factors can partially contribute to the pulpal reaction after restoration. Controversy surrounds evaluation of the effect of cytotoxicity and bacterial contamination on the histopathological biocompatibility examination of dental restorative materials.

While bonding to enamel is reliable, bonding to dentin entails a biological hazard for the dental pulp since dentin communicates with pulp by way of numerous tubules. The non-specific toxicity of the components of resin-based materials has been clarified (Geurtsen, 2000); the leaching out of unreacted components from photopolymerized resin-based materials has been documented as well (Santerre, Shajii & Leung, 2001). However, little is known about the potential toxicity of monomers during adhesive application before photopolymerization (Schedle & others, 1998). The pulpal diffusion of toxic materials through the dentin has also been reported by numerous studies (Hamid & Hume, 1997). The specific toxic effects on the pulp due to leaching of unpolymerized components (before setting and after polymerization) are not well known and the results remain controversial.

Several studies have assessed the pulpal biocompatibility of bonding materials in longer-term histopathological studies. However, little is known about the short-term dynamic response after adhesive application *per se*. In this study, the biological behavior of two commercially available adhesive resin systems was evaluated immediately after application on very thin pulpal dentin. In a previous study, the effect of an acetone-free commercial bond agent was examined on the vascular diameter of pulpal vessels by means of vitalmicroscopy (Iványi & others, 2000). In the current study, experiments comparing experimental data to those provided by an acetone-containing bond agent has been done.

Taylor (1950) introduced the method of vitalmicroscopy. Several authors (Pohto & Scheinin, 1958; Kozam & Burnett, 1959; Gängler, Hoyer & Krehan, 1982; Kim & others, 1984; Krehan & others, 1984; Nyárasdy & others, 1989) have since modified and improved this method. By vitalmicroscopy, it is possible to continuously measure the changes of the vessel diameters *in vivo*.

METHODS AND MATERIALS

Materials: Scotchbond Multi-Purpose Adhesive System (3M, Dental Products, St Paul, MN 55144, USA) comprised of Scotchbond Multi-Purpose Primer (contains 2 hydroxyethylmethacrilate HEMA/and watered solution of Vitremer copolymer), Scotchbond Multi-Purpose Adhesive (contains HEMA and Bisphenol-A-glycidyl methacrylate/BIS-GMA/) and Prime & Bond 2.1 (DeTrey, Dentsply, D-78467 Konstanz, Germany) were used with Scotchbond etchant (10 weight % maleic acid; 3M), as recommended by the manufacturer, in the two test groups.

Animal Preparation: The technique of vitalmicroscopy was used on the first lower incisor of 30 (three groups of 10) male Sprague-Dawley rats (weighing 333±9 g), anaesthetized with pentobarbitone sodium (Nembutal 35 mg/kg, ip, supplemented as required). Breathing was facilitated by tracheal cannulation and arterial blood pressure was monitored through a heparinized (1500 IU/ml) cannula inserted into the left femoral artery. Body temperature was maintained at 37°C using a heating lamp throughout the experiment. The depth of anesthesia was evaluated by applying pressure to a paw and observing changes in blood pressure. When such changes occurred, additional anaesthetic was administered.

The cartilaginous ligaments connecting the lower jaws were transected and the left part was cautiously cleared of soft tissues by gently pulling them toward the molars. This jaw was fixed with a circular polyester matrix strip by a dental matrix holder to ensure a rigid grip for further preparation. Special care was taken to minimize bleeding. The distal and mesial surfaces of the entire crown of the left lower incisor and some parts of the alveolar bone were ground away with a diamond fissure bur at about 15,000 rpm under constant saline cooling. After removing the enamel and part of the alveolar process, grinding was continued under a dissecting binocular microscope (1.6x6.3 Nikon, Tokyo, 100, Japan 100-8331) until the pulp vessels became clearly visible through the remaining dentin. Special care was taken to ensure uniform controlled preparation. The applied pressure was kept to a minimum and the exposed dentin was rinsed with a constant temperature (37°C) saline solution. When grinding was completed, a thin plate of dentin still remained intact over the delicate pulpal tissue.

Measurements were performed by means of a Nikon stereo light microscope (10x0.255+1x16 Optiphot-2, Tokyo, Japan, 100-8331) equipped with a video camera

(CCD-IRIS SSC-M370CE, Sony Corporation, Tokyo, Japan) and an image amplifier. To prevent dehydration or overheating, the exposed dentin was kept wet at a constant temperature by a thermostat-driven continuous saline rinsing throughout the experiment. After one hour of equilibration, the baseline vessel diameter of a suitable arteriole was measured on the monitor. Subsequently, bonding procedures or saline solution (control) was applied on the prepared surface. Two different commercial adhesive systems were used subsequently to conditioning as recommended by the manufacturer: Scotchbond Multi-Purpose Adhesive System (SMP), and Prime & Bond 2.1 (PB). Changes in vascular diameter of the pulpal arteriole were measured at 5, 15, 30 and 60 minutes. Changes of arterial diameter were expressed as percentage of baseline (mean±SE). Figure 1 shows the experimental set up.

Results are expressed as average ± SE. For statistical analysis, two-way ANOVA was applied with treatment and time as factors. Normal distribution was tested by the Kolmogorov-Smirnov test. Treatments were compared to control values by LSD method. A significance level of less than or equal to 0.05 was chosen to indicate statistical significance.

RESULTS

The systemic arterial pressure (85 Hgmm–110 Hgmm) measured in the femoral artery remained unchanged during the experiment both in the control and test animals. Under control conditions, the observed mean vessel diameter (38.6±1.22 µm) was stable during the entire experiment. The averages of the control measurements at different time periods were used for comparison with experimental data.

In the presence of acetone-free bond agent (SMP), the vessel diameter was increased at all time points measured (12.15±2.85%; 16.36±2.39%; 14.16±3.48%; 12.12±3.72%; ANOVA, $p<0.05$). In the presence of acetone-containing bonding agent (PB), a similar result was observed (10.56±2.27%; 16.13±2.94%; 17.88±2.54%; 14.54±3.16%; ANOVA, $p<0.05$).

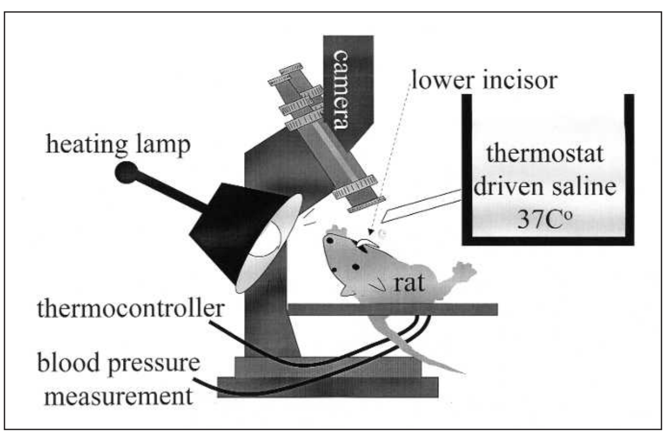


Figure 1. *Experimental setup for vitalmicroscopy.*

Increments of vessel diameter as compared to the control were statistically significant (ANOVA, $p<0.05$). There was no significant difference between the test groups and no signs of stasis, prestasis or any other alterations in the dental pulp of these groups.

DISCUSSION

Commercially available adhesive systems, depending on the product, may require the sequential application of one-to-three treatments with different substances prior to placing the restoration. Conditioners are used for removal of smear layer and to dissolve apatite crystals from the collagen matrix of dentin. Hydrophilic primers re-expand the collagen network (that is, susceptible to collapse following the loss of inorganic matrix) and promote the diffusion rate of bonding monomers into demineralized dentin (Munksgaard & Asmussen, 1984; Nakaoki & others, 2000). Bonding agents establish a bind between the primed dentin surface and the composite resin. Dentin adhesives are supposed to adhere to dentin, hence, in order to increase the binding surface, a liner to protect the pulp is not used.

In this study, two products of popular adhesive resin systems were tested. The adhesive system SMP is a fourth-generation water-based adhesive containing 2-hydroxy-ethyl-methacrylate (HEMA). HEMA, as an example of a hydrophilic primer in water, is used to help to improve the infiltration of adhesive monomers into demineralized dentin by wetting the surface of collagen fibers. On the other hand, it maintains the collagen network in an expanded state by stiffening the collagen fibers (Maciel & others, 1996; Pashley & others, 1996).

PB is a fifth-generation adhesive, where the primer and bonding agent are combined into one bottle with acetone as a solvent. Acetone, with its water displacing potential, chemically dehydrates the demineralized dentin (Pashley & others, 1996) and allows deeper infiltration of the bonding monomers (Tay & Pashley, 2001). The composition of the two bonding systems seems to be different, in particular, considering the acetone content of PB.

In this study, the pulpal reaction after applying acetone-containing bonding agent is comparable to that of the acetone-free one, despite the cytotoxicity of acetone (Raje, 1980). It can, therefore, be concluded that the thin layer of hydrophilic dentin over the pulp seems to diminish the diffusion of acetone to the pulp. In the presence of both adhesive systems, a similar degree of vasodilatation was observed, which is not necessarily regarded as a toxic reaction. The increased pulpal circulation might be a physiological protective response

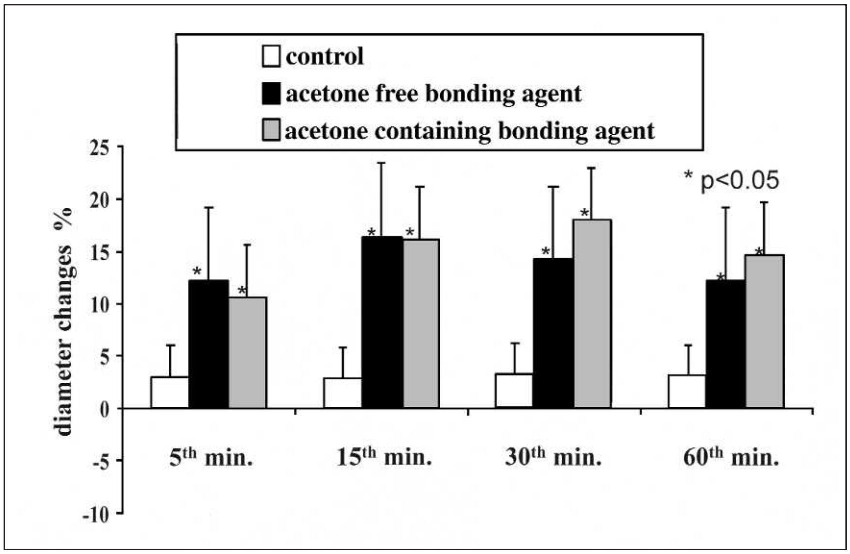


Figure 2. *Alterations (%) in arteriole diameters due to the application of acetone-free bond agent (SMP, black bars) or acetone-containing bonding agent (PB, gray bars) or saline (empty bars=control group), as determined by vitalmicroscopy in rat dental pulp. Each column represents a mean value (± S.E.) expressed as % changes of the baseline vessel diameter. Asterisks denote significant differences between test and control groups (p<0.05).*

since it enhances the clearance of irritating material from the pulp (Pashley, 1996). There seems to be no direct, harmful, acute effect of either bonding agent on the dental pulp. This is supported by the finding that acute, irreversible circulatory changes, such as stasis, prestasis (indicating pulpal necrosis) have not been observed.

Various co-factors determine the pulpal biocompatibility of a resin-based material. The remaining dentin thickness (RDT) over the pulp has an essential protective effect against the permeability of leachable toxins from restorative materials to pulpal tissue (Hamid & Hume, 1997; Hebling, Giro & Costa, 1999). It is difficult to measure the RDT during cavity preparation. Vitalmicroscopy provides the possibility of appraising the RDT adequately by the distinctness with which the pulpal vessels are visible under light microscope through the dentin. The extremely thin RDT used in this study mimics the clinical situation during indirect pulp capping procedures or during cavity preparation with undetected pulpal proximity. This is a clinical situation, where the possible cytotoxicity of restorative materials may readily manifest in the pulpal circulation.

In very deep dentin, the applied low viscosity adhesive materials have been seen to reach into the peripheral pulp (Tay & others, 1994), indicating the loss of junctional complexes between adjacent odontoblasts. However, little histopathological evidence of inflammation around resin globules in the pulp was found (Tay & others, 1994). On the other hand, sponges embedded in SMP and implanted into connective tissue of rats showed intense inflammatory response (Costa & others, 1999). On cell cultures of human pulps, SMP showed "not significant" toxicity (Neroni & others, 1990). No acceptable biocompatibility has recently been observed related to the application of SMP and PB on exposed human pulp (Cehreli & others, 2000); however, Goracci, Mori & Bazzucchi (1995) found no alteration of the pulp after SMP treatment of deep cavities. Grieve, Alani & Saunders (1991) observed various pulpal responses due to SMP. There are still several contradictory results, probably partly caused by the variation in RDT and partly due to the confounding bacterial leakage.

In dental adhesive systems, conditioning procedure precedes the direct application of bonding components to the prepared dentin. The insignificant effect of dentinal etching on the pulpal circulation has already been documented (Iványi & others, 2001). Dentinal conditioning increases the permeability of dentin (Pashley & others, 1983) and enhances the penetration of the applied unpolymerized bonding agent to the pulp (Hamid, Sutton & Hume, 1996). The polymerized bonding material plugs the dentinal tubules, thus defending the pulp from the subsequent persistent penetration of leachable toxic components of composite filling materials (Stanley, 1994). Hence, the application of adhesive materials (after conditioning) has been considered by some to be more significant in causing pulpal injury than resin filling material.

In summary, there was no statistical difference between the two commercial bondmaterials either in the degree of vasodilatation or the absence of irreversible changes. Thus, the acute pulpal circulatory effect of bonding agents does not depend on their acetone content.

Vitalmicroscopy, a very difficult time- and money-consuming method, permits the detailed continuous evaluation of local and acute circulatory changes in dental pulp. Changes in distinct vessels can be observed *in vivo* during the investigation. However, this model does not allow for chronic observations. Because of the short-term (60-minute) evaluation period, the effect of chronic thermal, mechanical and bacterial irritation due to leakage at the cavity margins is excluded, thus, the observed effect is solely caused by the bonding agent per se. As the toxic effect of unpolymerized adhesive material is greatest during and immediately after application (Schedle & others, 1998; Kaga & others, 2001), continuous *in vivo* investigation of the immediate pulpal effect of bonding agent still provides valuable information to the findings of the recommended histopathological biocompatibility usage tests.

CONCLUSIONS

The results of this study show that although composite resin bonding agents applied onto a thin layer of dentin have an acute vasodilatating effect, they do not provoke irreversible stasis-like changes. During the period tested, no difference between the pulpal effect of acetone-containing and acetone-free bonding material was detected.

Acknowledgements

This study was supported by the grants: OTKA T023937 and ETT T-13 453/96.

(Received 20 September 2001)

References

Bergenholtz G (2000) Evidence for bacterial causation of adverse pulpal responses in resin-based dental restorations *Critical Reviews in Oral Biology and Medicine* **11(4)** 467-480.

Brännström M, Vojinovic O & Nordenvall KJ (1979) Bacteria and pulpal reactions under silicate cement restorations *The Journal of Prosthetic Dentistry* **41(3)** 290-295.

Cehreli ZC, Turgut M, Olmez S, Dagdeviren A & Atilla P (2000) Short term human primary pulpal response after direct pulp capping with fourth-generation dentin adhesives *The Journal of Clinical Pediatric Dentistry* **25(1)** 65-71.

Costa CA, Teixeira HM, do Nascimento AB & Hebling J (1999) Biocompatibility of an adhesive system and 2-hydroxyethylmethacrylate *ASDC Journal of Dentistry for Children* **66(5)** 337-342.

Gängler P, Hoyer I & Krehan F (1982) [Pulp protection and Evicrol fillings in a vital-microscopic test on the endodontium] *Zahn-, Mund-, und Kieferheilkunde mit Zentralblatt* **70(4)** 339-344.

Geurtsen W (2000) Biocompatibility of resin-modified filling materials *Critical Reviews in Oral Biology and Medicine* **11(3)** 333-355.

Goracci G, Mori G & Bazzucchi M (1995) Marginal seal and biocompatibility of a fourth-generation bonding agent *Dental Materials* **11(6)** 343-347.

Grieve AR, Alani A & Saunders WP (1991) The effects on the dental pulp of a composite resin and two dentin bonding agents and associated bacterial microleakage *International Endodontic Journal* **24(3)** 108-118.

Hamid A & Hume WR (1997) The effect of dentin thickness on diffusion of resin monomers *in vitro Journal of Oral Rehabilitation* **24(1)** 20-25.

Hamid A, Sutton W & Hume WR (1996) Variation in phosphoric acid concentration and treatment time and HEMA diffusion through dentin *American Journal of Dentistry* **9(5)** 211-214.

Hebling J, Giro EM & Costa CA (1999) Human pulp response after an adhesive system application in deep cavities *Journal of Dentistry* **27(8)** 557-564.

Iványi I, Balogh ÁE, Rosivall L & Nyárasdy I (2000) *In vivo* examination of the Scotchbond Multi-Purpose Dental Adhesive System in rat (vitalmicroscopic study) *Operative Dentistry* **25(5)** 418-423.

Iványi I, Kispélyi B, Fazekas A, Rosivall L & Nyárasdy I (2001) The effect of acid etching on vascular diameter of pulp-vessels in rat incisor (vitalmicroscopic study) *Operative Dentistry* **26(3)** 248-252.

Kaga M, Noda M, Ferracane JL, Nakamura W, Oguchi H & Sano H (2001) The *in vitro* cytotoxicity of eluates from dentin bonding resins and their effect on tyrosine phosphorylation of L929 cells *Dental Materials* **17(4)** 333-339.

Kim S, Lipowsky HH, Usami S & Chien S (1984) Arteriovenous distribution of hemodynamic parameters in the rat dental pulp *Microvascular Research* **27** 28-38.

Kozam G & Burnett GW (1959) Blood circulation in the dental pulp *Journal of the American Dental Association* **59** 458.

Krehan F, Gängler P, Hoyger I & Koch IL (1984) [Vital microscopic examination of the pulp reaction to Proviso-blend in an acute biological test] *Deutsche Zahnarztliche Zeitschrift* **39(7)** 508-511.

Maciel KT, Carvalho RM, Ringle RD, Preston CD, Russell CM & Pashley DH (1996) The effects of acetone, ethanol, HEMA, and air on the stiffness of human decalcified dentin matrix *Journal of Dental Research* **75(11)** 1851-1858.

Munksgaard EC & Asmussen E (1984) Bond strength between dentin and restorative resins mediated by mixtures of HEMA and glutaraldehyde *Journal of Dental Research* **63(8)** 1087-1089.

Nakaoki Y, Nikaido T, Pereira PN, Inokoshi S & Tagami J (2000) Dimensional changes of demineralized dentin treated with HEMA primers *Dental Materials* **16(6)** 441-446.

Neroni M, Regad C, Christen O, Thoenen S & Holz J (1990) [6 dentin adhesive products subjected to controls *in vitro*] *Journal de Biologie Buccale* **18(4)** 271-285.

Nyárasdy I, Bánóczy J, Varga B, Folly G & Stark E (1989) [The effect of composite filling materials on the diameter of the blood vessels of the dental pulp in rat teeth] *Fogorvosi Szemle* **82(5)** 149-152.

Pashley DH (1996) Dynamics of the pulpo-dentin complex *Critical Reviews in Oral Biology and Medicine* **7(2)** 104-133.

Pashley DH, Kepler EE, Williams EC & Okabe A (1983) The effects of acid etching on the in-vivo permeability of dentin in the dog *Archives of Oral Biology* **28(7)** 555-559.

Pashley DH, Sano H, Yoshiyama M, Ciucchi B & M CR (1996) The effects of dentin binding procedures on the dentin/pulp complex In *Dentin/pulp complex* ed K T, pp 193-201 Tokyo: Quintessence Publishing Company.

Pohto M & Scheinin A (1958) Microscopic observation on living dental pulp. I. Method for intravital study of circulation in rat incisor pulp *Acta Odontologica Scandinavica* **16** 303.

Raje RR (1980) *In-vitro* toxicity of acetone using coronary perfusion in isolated rabbit heart *Drug and Chemical Toxicology* **3(3)** 333-342.

Santerre JP, Shajii L & Leung BW (2001) Relation of dental composite formulations to their degradation and the release of hydrolyzed polymeric-resin-derived products *Critical Reviews in Oral Biology and Medicine* **12(2)** 136-151.

Schedle A, Franz A, Rausch-Fan X, Spittler A, Lucas T, Samorapoompichit P, Sperr W & Boltz-Nitulescu G (1998) Cytotoxic effects of dental composites, adhesive substances, compomers and cements *Dental Materials* **14(6)** 429-440.

Stanley HR (1994) Dental iatrogenesis *International Dental Journal* **44(1)** 3-18.

Tay FR, Pang KM, Gwinnett AJ & Wei SH (1994) A scanning electron microscopic study of the extent of resin penetration into human coronal dentin following a total etch technique, *in vivo Cells and Materials* **4** 317-329.

Tay FR & Pashley DH (2001) Aggressiveness of contemporary self-etching systems. I: Depth of penetration beyond dentin smear layers *Dental Materials* **17(4)** 296-308.

Taylor AC (1950) Microscopic observation of the living tooth pulp *Science* **111** 40.

©Operative Dentistry, 2002, **27**, 373-380

Effect of Thickness of Flowable Resins on Marginal Leakage in Class II Composite Restorations

H Malmström • M Schlueter
T Roach • ME Moss

Clinical Relevance

The thickness of the flowable resin composite (FRC) gingival increment may affect the marginal leakage supra-cemento-enamel junction (CEJ) in posterior Class II resin composite restorations; however, the addition of a FRC gingival increment may not change the marginal leakage sub-CEJ compared to hybrid resin composite used alone.

SUMMARY

Despite limited scientific evaluation, there is an increased use of low elastic modulus flowable resin composite (FRC) as a stress-relieving gingival increment in Class II restorations. This study compared marginal leakage in preparations with gingival margins in enamel or dentin/cementum (sub-CEJ and supra-CEJ) after FRC was used as a gingival increment to hybrid resin composite used alone. In addition, the extent of leakage around restorations with or without the use of FRC gingival increments when light curing the resin composites from occlusal direction only or buccal, lingual and occlusal directions was compared. Sixty extracted human molars were prepared with two identical Class II (MO and OD) preparations (30 were 1 mm sub-CEJ and 30 were 1 mm supra-CEJ) and randomly assigned to six groups. After etching, dentin-bonding agent was applied to all prepared tooth surfaces according to the manufacturer's specifications. One of three different thicknesses of FRC (0.5 mm, 1 mm or 2 mm) was placed on the gingival floor, cured and a hybrid resin composite was placed occlusally to complete the restoration. The control preparation on each tooth was restored in the same manner, except that a hybrid resin composite was used for both the gingival and occlusal increments. The restored teeth were thermocycled (300 cycles), then immersed in 50% silver nitrate prior to the hemi-section and measured for leakage under a light microscope. The data were evaluated using paired measures analysis of variance (ANOVA). Most of the occlusal margins showed no leakage, while almost every gingival margin demonstrated some silver nitrate penetration regardless of whether it was located sub or supra-CEJ, although significantly less leakage was found in restorations with supra-CEJ margins (p=0.0001). Among supra-CEJ restorations, there was a pronounced reduction in leakage as

*Hans S Malmström, DDS, program director and division chief of General Dentistry, Eastman Dental Center, University of Rochester

Marc Schlueter, DDS, resident, Department of Orthodontics, University of Rochester

Terence Roach, research assistant, Advanced Education in General Dentistry Program, University of Rochester

Mark E Moss, DDS, PhD, assistant professor, Eastman Department of Dentistry, University of Rochester

*Reprint request: 625 Elmwood Ave, Rochester, New York, 14620-2989; e-mail: Hans_malmstrom@urmc.rochester.edu

FRC thickness increased (p=0.0005). In the teeth restored with the gingival-margin located supra-CEJ, the 2 mm thickness FRC gingival increment showed significantly less leakage (p<0.01) compared with the 0.5 mm thickness of FRC gingival increment. The direction of the curing light did not affect the extent of leakage (p>0.05). The use of FRC material as a gingival increment sub-CEJ in posterior hybrid resin restorations produced no significant difference in leakage (p>0.05). The results of this study indicated that restorations located supra-CEJ (with gingival margins in enamel) with 2 mm thick FRC gingival increments demonstrated significantly less leakage than did those with 0.5 mm FRC. When the margin of the restoration was located sub-CEJ (in dentin/cementum), neither the thickness nor the presence of FRC as a gingival increment significantly influenced the marginal leakage.

INTRODUCTION

Marginal leakage at the tooth-restoration interface is one of the clinical problems associated with using resin composites in direct Class II composite restorations (Bayne & others, 1998). Marginal leakage may provoke sensitivity due to an interfacial hydrodynamic phenomenon (Brännström & Nyborg, 1971; Brännström, 1986) and can lead to colonization of micro-organisms and subsequent pulpal infection (Brännström & Vojinovic, 1976). As a result, the sealing capabilities of dentin bonding systems at the composite/dentin interface have been extensively investigated, usually *in vitro*.

In vitro studies have indicated that interfacial stress during the hardening shrinkage of a resin composite is positively correlated with the rigidity of the material. The elastic modulus increases as the polymerization reaction proceeds (Davidson & de Gee, 1984; Braem & others, 1987). Studies have shown that curing stress has been dependent on the ratio of the bonded to free, unbonded surface area of the tooth (Feilzer, de Gee & Davidson, 1987), the material properties of the resin composites (Hegdahl & Gjerdet, 1977; Feilzer, de Gee & Davidson, 1990a) and the amount of compliance of the substrate materials (Kemp-Scholte & Davidson, 1988; Labella & others, 1999). The material's ability to undergo plastic flow during the early phases of polymerization and slower rates of polymerization reactions may reduce early interfacial stress build-up (Davidson & de Gee, 1984; Kemp-Scholte & Davidson, 1988; Feilzer & others, 1990a; Derhami, Coli & Brännström, 1995) and later, hygroscopic expansion may relieve the polymerization shear stress (Feilzer, de Gee & Davidson, 1990b).

In addition to the material properties of bonding systems and the resin composite used, studies suggest that many clinical variables, such as cavity design and depth, operative techniques, mode of application of the bonding systems and insertion and curing techniques of the resin composite significantly influence the bond (interface) between tooth structure and restorative material (Lutz, Krejci & Schüpbach, 1993; van Dijken, Horstedt & Waern, 1998; Hoelscher & others, 2000).

Gap formation and subsequent leakage caused by polymerization shrinkage stresses and differences between the physical properties of tooth structure and currently available restorative materials have not been completely eliminated. Gap formation is especially prevalent if gingival margins are located apical to the cementoenamel junction (CEJ) in dentin (Prati & others, 1994; Derhami & others, 1995; da cunha Mello & others, 1997).

A common theory suggests that since the polymerization reaction is dependent on light intensity, and light intensity decreases as it penetrates the composite, the shrinkage vector will be directed towards the light source. While light source orientation may affect the shrinkage vector (Hoelscher & others, 2000), this factor may serve as a weak component in a complex of factors. Nevertheless, it has stimulated investigators to light-cure composite materials from different directions to evaluate microleakage. Neiva & others (1998) found no difference when light curing the composite restoration supra CEJ (with margins in enamel) from the occlusal direction alone compared to the occlusal and buccal direction. When curing restorations apically of the CEJ, the occlusal light curing direction alone demonstrated less gingival marginal leakage.

To improve marginal adaptation, better treatment techniques and new materials such as FRC, introduced in late 1996, are continually being developed. Flowable resin composites have two desirable clinical handling characteristics that previously available materials did not: non-stickiness and fluid injectability (Bayne & others, 1998). Although manufacturers have recommended that flowable resin composite can be used for a wide range of applications (Bayne & others, 1998), the most common use is as a gingival increment in Class II posterior resin composite restorations.

It has been suggested that since flowability is mainly achieved by lowering the filler loading, flowable composites may shrink far more than the current non-flowable composites (Bayne & others, 1998). For the same reason, the FRC can be expected to be less rigid than conventional hybrid resin composites. Labella & others (1999) reported on polymerization shrinkage and found the values ranged from 1.9% to 13.5% for the adhesive resins, flowable, microfilled and hybrid resin composite materials studied. The flowable material's polymerization shrinkage ranged from 3.65 to

6.0%. The adhesive resins demonstrated the highest polymerization shrinkage (up to 13.5%).

Limited research data is available regarding using FRC as a gingival increment in Class II restorations. In regard to leakage, Payne (1999) suggested that flowable resin composite as a base is superior to injectable glass ionomer with or without bonding agent. In another study, Chuang & others (2001) compared leakage in Class II composite restorations (supra-CEJ) with and without flowable composite linings at the apical margin in enamel and found no significant difference. When Ferdianakis (1998) compared the leakage of a FRC material to a hybrid resin composite material in Class I lesion restorations, he found significantly less leakage in teeth restored with FRC.

This study compared the leakage of Class II restorations with gingival margins sub and supra (CEJ) restored with different thicknesses of flowable resin composites on the gingival floor serving as the first increment, and hybrid resin composites placed occlusally, with similar restorations made using hybrid resin composites alone as controls. Also evaluated was the effect on leakage when resin composite restorations are cured from the occlusal direction only compared to buccal, lingual and occlusal directions.

METHODS AND MATERIALS

Study Subjects and Materials

Sixty caries-free, restoration-free extracted lower human molars were collected and initially stored in a 0.005% thymol solution. For infection control purposes, these teeth were sterilized with ethylene oxide, stored in distilled water and refrigerated until used. Prior to the study, the teeth were reviewed for any enamel defects. The restorative materials selected for this study were All Bond-2 (BISCO, Schaumburg, IL 60193, USA) as dental adhesive, Tetric Flow (Lot #546328, Ivoclar-Vivadent, Amherst, NY 14228, USA) flowable resin composite and Tetric Ceram (Lot #546313/546307/546317 Ivoclar-Vivadent) hybrid resin composite. The flexural modulus of Tetric Flow was 5300 MPa, the flexural modulus of Tetric Ceram was 9400 MPa and the percent filler by weight was 67.8% and 78.6%, respectively.

Cavity Preparation

The teeth were randomly assigned to six groups (Figure 1). A high-speed handpiece (Midwest Dental Products, Des Plaines, IL 60018, USA) with water coolant and a round end cylinder bur with a head diameter of 1 mm and a head length of 4 mm (D838, Brassler, Savannah, GA 31419, USA) performing at 350000-400000 RPM (with 35 psi compressed air) was used to prepare all teeth with two conservative Class II (MO and OD) cavity preparations (30 teeth with cervical margins 1 mm sub-CEJ and 30 teeth with cervical margins 1 mm supra-CEJ). The dimensions of the preparations were 2 mm buccal-lingual width and 1.5 mm mesial-distal width.

Restorative Procedure

A piece of clear matrix (contact molar bands, Ivoclar-Vivadent) was placed around the tooth and the intended depth of the gingival increment for the experimental and control restoration was measured and marked on the matrix band (Figure 2). Each tooth was embedded in alginate, contacting one tooth mesially and one tooth distally (Figure 3). By sliding the adjacent teeth (held in hardened silicon) toward the experimental tooth (held in soft alginate), mesial and distal contacts could be achieved while the matrix remained in position. The same model and adjacent teeth were used for each restoration. After etching with Uni-Etch (32% phosphoric acid, BISCO) for 20 seconds, washing and drying (leaving moist dentin), five coats of primer (All-Bond 2 [A+B], BISCO) were applied to both the experimental and control cavity preparations. Following the final coat, the primed surface was air dried for five seconds, leaving a shiny surface. A thin layer of dentin/enamel bonding resin (All-Bond 2 [A+B], BISCO) was applied to all cavity preparations and light cured for 20 seconds.

One of three different thicknesses of flowable resin composite (0.5 mm, 1 mm or 2 mm of Tetric Flow, Ivoclar-Vivadent) was placed on the interproximal gingival floor of experimental preparations and cured for 60 seconds from an occlusal direction only or for 20 seconds from the buccal direction, followed by the lingual direction for 20 seconds and finally, the occlusal direction for 20 seconds. A hybrid resin composite (Tetric Ceram, Ivoclar-Vivadent) was placed on top of this FRC gingival increment to complete the restoration. The second preparation on each tooth was used as a control. In the control restoration, a hybrid resin composite (Tetric Ceram) was placed on the interproximal gingival floor with the same thickness (0.5 mm, 1 mm or 2 mm) and was cured in the same manner as the FRC gingival increment in the experimental restoration of the same tooth. An additional increment of this hybrid resin composite was then placed on top of the first layer to complete the restoration. This occlusal (top) layer of hybrid resin composite in both the experimental and control restorations was light-cured in the same manner as the first layer of material (either FRC or hybrid resin composite). The curing light used was Optilux 500 (Kerr, Orange, CA 92867, USA) and the light intensity was 600 mW/cm^2. Finishing and polishing was conducted with a fluted carbide-finishing bur (Brassler) and medium fine and extra fine-grit Sof-Lex flexible disks (3M Dental Products, St Paul, MN 55144, USA).

Thus, there were 24 study groups (with n=5 in each group) defined by whether the cervical margin of the restoration was placed supra-CEJ or sub-CEJ (with n=30 in each group) by thickness of the experimental or the control material that lined the gingival floor of the restoration (0.5 mm, 1.0 mm or 2.0 mm, with n=10 in each group) and by the direction of the curing light (buccal-lingual-occlusal or occlusal only, with n=5 in each group) (Figure 1).

Evaluation of Leakage

The restored teeth were thermocycled (300 cycles, with 45 seconds dwell time at 5°C and at 55°C). Prior to immersion in 50% silver nitrate, the root apices were obturated with wax, and the tooth structure surrounding the restoration (within 1 mm of the margins) was sealed with two layers of nail varnish. In a darkroom, the samples were placed in the silver nitrate solution for four hours, they were then placed in distilled water and exposed to light (100-watt light bulb at a distance of six inches) for eight hours. After the silver nitrate treatment, the teeth were washed in distilled, deionized water and stored in a humidor. For evaluation, the teeth were hemisected by a low speed saw (Gillings-Hamco thin sectioning machine, Hamco Machines, Rochester, NY 14622, USA) in a buccal-lingual plane, followed by a sectioning in mesial-distal plane. The sectioned teeth were polished using an Ecomet2 Grinder-Polisher (Buehler Ltd, Lake Bluff, IL 60044, USA) with a 600 grit carbimet paper disc (Buehler Ltd) for five seconds, rinsed in distilled deionized water for three minutes and polished further by a 1200 grit carbimet paper disc (Buehler Ltd) for 15 seconds. All polishing was done under a stream of distilled, deionized water. An Olympus System Light Microscope (Olympus Optical Co, Ltd, Tokyo, Japan), in combination with the Optimas Image Analysis Program (Media Cybernetics, Silver Spring, MD 20910, USA) was used to measure the depth of the silver nitrate penetration at the occlusal and cervical tooth-restoration interface. Silver nitrate penetration along the tooth-restoration interface was compared to the total length of the tooth-restoration interface and expressed as a percentage.

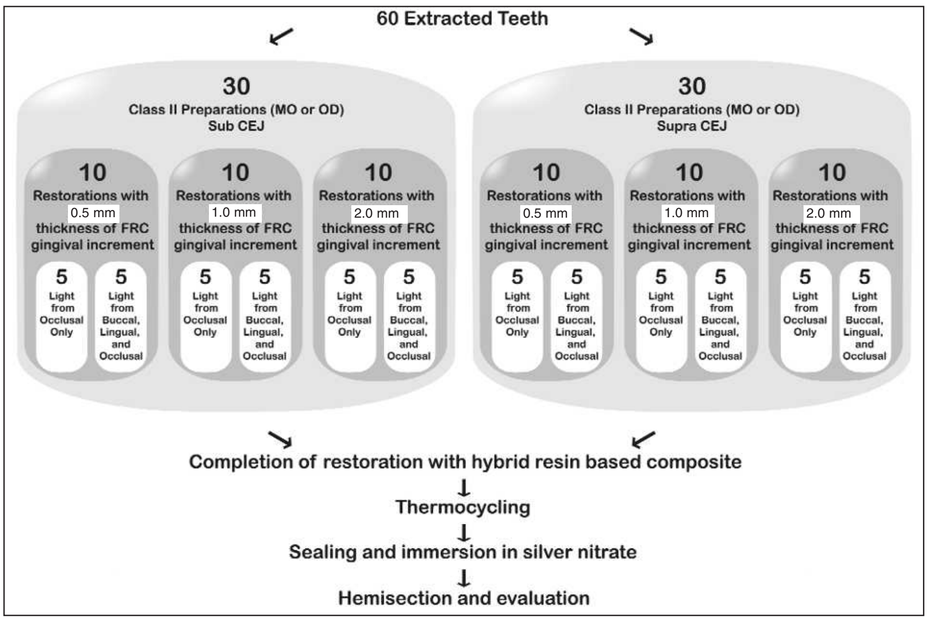


Figure 1. *Sixty extracted teeth were randomly assigned to six groups and a MO and DO cavity preparation was created on each tooth. The experimental restorations were randomly assigned to either the MO or DO preparation and are demonstrated below. The remaining preparation on each tooth was treated as a control restoration (with the same conditions but using hybrid resin composite instead of FRC). All restorations were finally completed with a second increment using hybrid resin composite.*

Figure 2. *The intended depth of FRC was measured and marked on a clear matrix band prior to placement between adjacent teeth.*

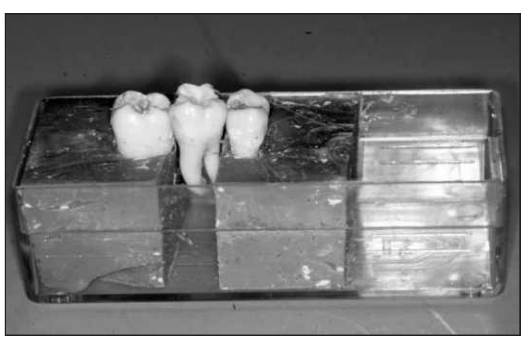


Figure 3. *Experimental setup. Tooth to be restored (center) was placed in alginate, and adjacent teeth were moved into position.*

Statistical Analysis

The analysis plan was to examine leakage among sub-CEJ and supra-CEJ restorations. The focus was on the thickness of flowable resin composite material. A secondary analysis was performed to assess the effect of the direction of the light source (occlusal only vs buccal-lingual-occlusal). Each tooth had both an experimental and a control restoration, so the difference in leakage for each tooth was tabulated as the dependent variable. Independent variables were resin thickness on the gingival floor (0.5 mm, 1.0 mm, 2.0 mm) and curing light direction (occlusal versus buccal-lingual-occlusal). The authors also tested whether leakage was greater in restorations that were sub-CEJ compared to restorations that were supra-CEJ. The data were evaluated using paired measures analysis of variance (ANOVA) to contrast differences in means for percentage of overall cervical leakage between the experimental restoration and the control restoration in each tooth within the 24 groups. Statistical significance level of alpha = 05 was preset. Global F-tests were conducted among sub-CEJ restorations and supra-CEJ restorations using resin thickness and curing light direction as independent variables.

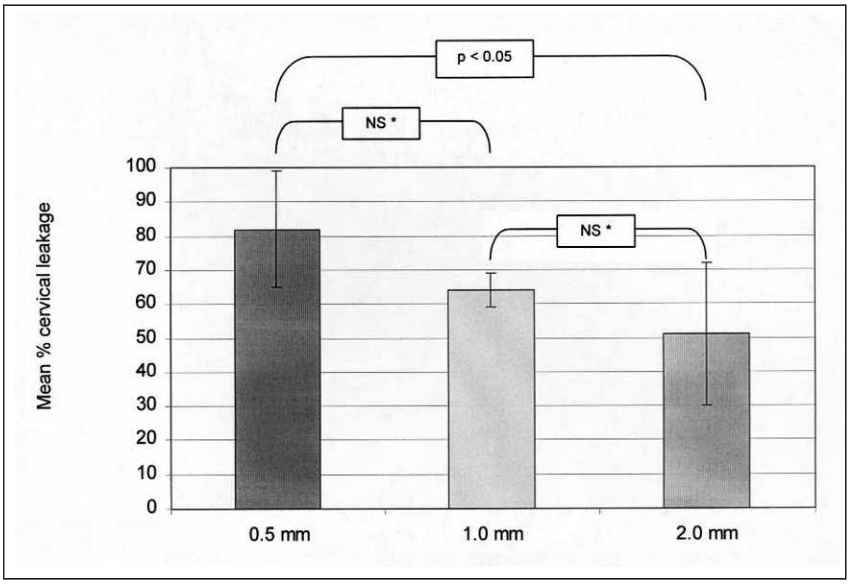


Figure 4. *The effect of the three thicknesses of FRC gingival increment on the mean percentage of overall cervical leakage in restorations with supra-CEJ cervical margins. Error bars represent standard deviation. (*Groups did not differ significantly,* $p>0.05$*).*

Table 1: *Cervical Margin Leakage: Thickness of Material*

Thickness of Resin on Gingival Floor of Restoration	Control Leakage (SD)	Experimental % % Leakage (SD)
Supra-CEJ Cervical Margin		
0.5 mm	59 (23)	82 (17)**
1.0 mm	68 (8)	64 (5)
2.0 mm	63 (7)	51 (21)**
Overall Supra-CEJ Mean	63 (15) *	66 (20)***
Sub-CEJ Cervical Margin		
Thickness of Resin on Gingival Floor of Restoration	Control Leakage (SD)	Experimental % Leakage (SD)
0.5 mm	87 (9)	76 (16)
1.0 mm	86 (15)	79 (20)
2.0 mm	84 (14)	83 (11)
Overall Sub-CEJ Mean	86 (13) *	79 (16) ***

Cervical margin leakage expressed as a mean (standard deviation) percentage of the total length of the tooth-restoration interface. Among supra-CEJ restorations, there was a pronounced reduction in leakage of the experimental material relative to control as thickness increased (paired measures analysis of variance, $p=0.0005$*). Among sub-CEJ restorations, there were no differences by thickness of the material. However, it is interesting to note that the experimental group showed statistically non-significant difference of about 7% less leakage than the control group overall (paired measures analysis of variance,* $p=0.10$*).*

The 12 study groups (with n=10 in each group) were defined by whether the proximal box of the restoration was placed supra-CEJ or sub-CEJ, and by the thickness of the experimental or control material that lined the gingival floor of the restoration (0.5 mm, 1.0 mm, or 2.0 mm). Within each study group, there were 2 sub-groups (n=5 each) defined by the direction of the curing light (buccal-lingual-occlusal or occlusal only).

, **, * indicate statistical significance,* $p<0.05$

RESULTS

Most (90.8%) of the occlusal margins showed no leakage, while all gingival margins demonstrated silver nitrate penetration regardless of location, sub or supra-CEJ. Significantly less leakage ($p<0.001$) was found in teeth restored 1 mm supra-CEJ compared to sub-CEJ both in the experimental and control groups (Table 1). For the gingival margins, distributions of the percentage of leakage were plotted and determined to be normal. None were significantly skewed. The relatively small standard deviations presented in Table 2 show that the means are good measures of central tendency. Among the restorations with the supra-CEJ margins, there was a statistically significant reduction in leakage in the experimental groups with FRC gingival increment relative to control (without FRC gingival increment) as thickness increased ($p=0.0005$). Among subgingival restorations, there were no statistically significant differences in regard to leakage when increasing the thickness of the gingival increment either in the control or experimental group. However, it was interesting to note that the experimental group showed a statistically non-significant difference of about 7% less leakage than the control group overall ($p=0.10$). The direction used to cure the resin composites did not affect the extent of leakage ($p>0.05$) (Table 2). Horizontal enamel cracks were observed in nine of the experimental restorations (30%) and eight of the control restorations (27%). No statistically significant difference in regard to marginal leakage was found between the samples with and without cracks.

DISCUSSION

There are no accepted scientific methods to correlate *in vitro* leakage results to clinical findings (Roulet, 1994; Dejou, Sindres & Camps, 1996). Results of *in vitro* studies are often presumed to be more negative than *in vivo* studies, suggesting that leakage found *in vitro* should be regarded as a theoretical maximum amount of leakage that may or may not occur *in vivo* (Pashley, 1990).

The results of this study do not disagree with the findings of Chuang & others (2001), who were unable to demonstrate a leakage

Table 2: *Cervical Margin Leakage: Curing Light Direction*

Experimental Groups											
Supra-CEJ						Sub-CEJ					
Occlusal Only			Buccal, Lingual, Occlusal			Occlusal Only			Buccal, Lingual, Occlusal		
0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0
80 (17)	66 (07)	39 (25)	83 (20)	63 (02)	62 (03)	69 (09)	90 (07)	82 (13)	84 (19)	68 (23)	84 (09)
Control Groups											
Supra-CEJ						Sub-CEJ					
Occlusal Only			Buccal, Lingual, Occlusal			Occlusal Only			Buccal, Lingual, Occlusal		
0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0
67 (20)	64 (07)	62 (08)	51 (25)	72 (08)	64 (06)	90 (08)	79 (17)	78 (17)	84 (10)	93 (09)	89 (08)

Means and standard deviations of leakage expressed as percentage of the total length of the tooth-restoration interface in the 24 study groups (with n=5 in each group).

The 24 study groups (with n=5 in each group) were defined by whether the cervical margin of the restoration was placed supra-CEJ or sub-CEJ, by the thickness of the experimental or control material that lined the gingival floor of the restoration (0.5 mm, 1.0 mm, or 2.0 mm), and by the direction of the curing light (buccal-lingual-occlusal or occlusal only).

difference between the presence or absence of FRC gingival increments in Class II restorations with supra-CEJ margins. The effect of the thickness of the FRC gingival increment was not evaluated in their study (all gingival increments were 1-1.5 mm thick). The results of the current study indicate that the thickness of the FRC gingival increment may have an effect on leakage in restorations with supra-CEJ margins.

In this study, only one vertical sectioning was performed in the mesial-distal direction. It has been suggested that a more accurate way to evaluate total leakage is to completely remove the restoration and evaluate the total amount of leakage, as this can vary from different sections (Hilton, Schwartz & Ferracane, 1997).

Since great variability exists in the amount of filler material and material composition, these results cannot be generalized to include other combinations of adhesive flowable and hybrid resin composite materials. Labella & others (1999) have demonstrated that the elastic moduli for adhesive resins and flowable composites and microfills were relatively low compared to the hybrid materials and that there were significant differences within these groups of materials. In the present study, a non-filled adhesive resin was used that has a significantly lower modulus of elasticity than a filled material.

In the current study, the authors demonstrated reduced leakage when increasing the thickness of the flowable resin composites with cervical margins located supra-CEJ. This may be explained by a thicker layer of the low modulus of elasticity FRC reducing stress on the composite-tooth interface during polymerization, whereas a thinner layer of low modulus of elasticity FRC will provide a less stress-relieving effect. A resin composite material with lower modulus of elasticity and low viscosity, such as Tetric Flow, may also better undergo plastic flow during the early phases of polymerization. On the other hand, less filled materials have a higher polymerization shrinkage that could negatively effect marginal leakage especially if the bonding is inadequate (Labella & others, 1999.)

Kemp-Schulte & Davidson (1988, 1990a) found that marginal adaptation of Class V restorations can be improved and shrinkage stresses reduced by increasing the strain capacity of the restorative system. This was achieved by applying thicker intermediate layers of adhesive/liner between the cavity walls and adjacent resin composites. In this study, the thicker intermediate layer of the lesser filled Tetric Flow may increase the strain capacity of the restorations and, thereby, explain the reduced marginal leakage in the supra CEJ restorations.

Dejou & others (1996) discussed the importance of allowing an elastic bonding layer to form, especially when using a highly filled resin composite (such as Tetric Ceram) with high stiffness, to better withstand polymerization shrinkage stresses. In the current study, a non-filled dental adhesive (All-Bond 2) was used, with low modulus of elasticity that would allow for an elastic bonding layer. The Tetric Flow has a lower modulus of elasticity and is less filled and may assist in reducing the marginal leakage, as demonstrated in the thicker gingival increments of FRC, compared to a highly filled and stiff material such as Tetric Ceram alone (without a gingival increment of FRC). The fact that the effect of the thickness of FRC on marginal leakage was not found in the sub-CEJ restorations may be harder to explain, although the lesser bond strength to dentin may not sufficiently withstand polymerization stress. In this *in vitro* study model, adjacent teeth limited the placement and curing of the materials, which may better simulate the clinical situation but could affect the results. In addition, the mesial-distal depth of the preparation was 1.5 mm, which was significantly smaller than in other studies (Prati & others, 1994; Hilton & others, 1997) and may also explain the higher percentage of cervical marginal leakage in this study.

There was statistically significant greater leakage when the margin of the cavity was placed 1 mm sub-CEJ, and this may be explained by the fact that bonding only occurred in the dentin. In dentin, polymerization forces may exceed the bond strength. Ferrari & Davidson (1996) suggested that a direct Class II resin composite restoration can be placed in cavities surrounded by enamel, but when the margins are located in dentin, the quality of the margin was questionable. Other authors have suggested that the amount of curing time and direction of the light source could affect the leakage (Hoelscher & others, 2000). In this study, the direction of the light source did not demonstrate any effect regarding leakage. The light source was well calibrated and used for 120 seconds in total, thus, it is unlikely that the samples were not sufficiently cured.

Future *in vitro* studies should include simulation of occlusal stress forces to determine what effect this will have on leakage and stability of flowable resin composites. Kemp-Scholtz & Davidson (1990b) suggested that although more rigid resin composites such as hybrid resin composites may demonstrate greater curing contraction stresses, they may provide better support during functional loading. da cunha Mello & others (1997) demonstrated that functional loading of Class II restorations can further damage the cervical seal beyond what was caused by contraction stress alone.

Enamel fractures at the cervical margin 1 mm supra-CEJ occurred in 28.3% of the restorations. In an *in vivo* study, van Dijken & others (1998) reported a 5.6% enamel fracture rate at the cervical margin. This significant difference can possibly be explained by the minimal amount of enamel remaining at the cervical margin (1 mm thickness from the DEJ to the exterior surface), which may increase the fracture risk. The sectioning technique may also have influenced the results. Ideally, long-term clinical studies should be performed to evaluate the performance of FRC when used as a gingival increment in posterior resin composite restorations.

CONCLUSIONS

The sub-CEJ resin composite restorations demonstrated significantly more leakage compared to those with supra-CEJ gingival margins in restorations with and without FRC gingival increments. Neither the presence nor the thickness of flowable resin composite gingival increments significantly changed the extent of leakage in sub-CEJ Class II posterior resin composite restorations. Among supra-CEJ restorations, there was a pronounced reduction in leakage relative to the control (without FRC gingival increment) as the thickness of the gingival increment increased. When using FRC as a gingival increment in supra-CEJ restorations, 2 mm thicknesses demonstrated significantly less leakage compared to thicknesses of 0.5 mm FRC. Most (90.8%) of the occlusal margins showed no leakage, while all gingival margins demonstrated penetration of the silver nitrate solution regardless of the margin location, sub or supra-CEJ. The direction of the curing light had no influence on the marginal leakage.

(Received 20 September 2001)

References

Bayne SC, Thompson JY, Swift EJ Jr, Stamatiades P & Wilkerson M (1998) A characterization of first-generation flowable composites *Journal of the American Dental Association* **129(5)** 567-577.

Braem M, Davidson CL, VanHerle G, Van Doren V & Lambrechts P (1987) The relationship between test methodology and elastic behavior of composites *Journal of Dental Research* **66(5)** 1036-1039.

Brännström M (1986) The cause of postrestorative sensitivity and its prevention *Journal of Endodontics* **12(10)** 475-81.

Brännström M & Nyborg H (1971) The presence of bacteria in cavities filled with silicate cement and composite resin materials *Svensk Tandlakaretidskrift* **64(3)** 149-155.

Brännström M & Vojinovic O (1976) Response of the dental pulp to invasion of bacteria around three filling materials *ASDC Journal of Dentistry for Children* **43(2)** 83-9.

Chuang SF, Liu JK, Chao CC, Liao FP & Chen YH (2001) Effects of flowable composite lining and operator experience on microleakage and internal voids in Class II composite restorations *Journal of Prosthetic Dentistry* **85(2)** 177-183.

da cunha Mello FS, Feilzer AJ, de Gee AJ & Davidson CL (1997) Sealing ability of eight resin bonding systems in a Class II restoration after mechanical fatiguing *Dental Materials* **13(6)** 372-376.

Davidson CL & de Gee AJ (1984) Relaxation of polymerization contraction stresses by flow in dental composites *Journal of Dental Research* **63(2)** 146-148.

Dejou J, Sindres V & Camps J (1996) Influence of criteria on the results of *in vitro* evaluation of microleakage *Dental Materials* **12** 342-349.

Derhami K, Coli P & Brännström M (1995) Microleakage in Class II composite resin restorations *Operative Dentistry* **20(3)** 100-105.

Feilzer AJ, de Gee AJ & Davidson CL (1987) Setting stress in composite resin in relation to configuration of the restoration *Journal of Dental Research* **66(11)** 1636-1639.

Feilzer AJ, de Gee AJ & Davidson CL (1990a) Quantitative determination of stress reduction by flow in composite restorations *Dental Materials* **6(3)** 167-171.

Feilzer AJ, de Gee AJ & Davidson CL (1990b) Relaxation of polymerization contraction shear stress by hygroscopic expansion *Journal of Dental Research* **69(1)** 36-39.

Ferdianakis K (1998) Microleakage reduction from newer esthetic restorative materials in permanent molars *Journal of Clinical Pediatric Dentistry* **22(3)** 221-229.

Ferrari M & Davidson CL (1996) Sealing performance of Scotchbond Multi-Purpose-Z100 in Class II restorations *American Journal of Dentistry* **9(4)** 145-149.

Hegdahl T & Gjerdet NR (1977) Contraction stresses of composite resin filling materials *Acta Odontologica Scandinavica* **35(4)** 191-195.

Hilton TJ, Schwartz RS & Ferracane JL (1997) Microleakage of four Class II resin composite insertion techniques at intraoral temperature *Quintessence International* **28(2)** 135-144.

Hoelscher DC, Gregory WA, Linger JB & Pink FE (2000) Effect of light source position and bevel placement on facial margin adaption of resin-based composite restorations *American Journal of Dentistry* **13(4)** 171-175.

Kemp-Scholte CM & Davidson CL (1988) Marginal sealing of curing contraction gaps in Class V composite resin restorations *Journal of Dental Research* **67(5)** 841-845.

Kemp-Scholte CM & Davidson CL (1990a) Complete marginal seal of Class V resin composite restorations effected by increased flexibility *Journal of Dental Research* **69(6)** 1240-1243.

Kemp-Scholte CM & Davidson CL (1990b) Marginal integrity related to bond strength and strain capacity of composite restorative systems *Journal of Prosthetic Dentistry* **64(6)** 658-664.

Labella R, Lambrechts P, Van Meerbeek B & Vanherle G (1999) Polymerization shrinkage and elasticity of flowable composites and filled adhesives *Dental Materials* **15(2)** 128-137.

Lutz F, Krejci I & Schüpbach F (1993) Adhesive systems for tooth colored restorations: A review *Schweizerische Monatsschrift fur Zahnmedizin* **103** 537-549.

Neiva, IF, de Andrada MA, Baratieri LN, Monteiro S Jr & Ritter AV (1998) An in-vitro study of the effect of restorative technique on marginal leakage in posterior composites *Operative Dentistry* **23(6)** 282-289.

Pashley DH 4th (1990) Clinical considerations of microleakage *Journal of Endodontics* **16(2)** 70-7.

Payne JH (1999) The marginal seal of Class II restorations: Flowable composite resin compared to injectable glass ionomer *Journal of Clinical Pediatric Dentistry* **23(2)** 123-30.

Prati C, Tao L, Simpson M & Pashley DH (1994) Permeability and microleakage of Class II resin composite restorations *Journal of Dentistry* **22(1)** 49-56.

Roulet JF (1994) Marginal integrity: Clinical significance *Journal of Dentistry* **22(Supplement 1)** S9-12.

van Dijken JW, Horstedt P & Waern R (1998) Directed polymerization shrinkage versus a horizontal incremental filling technique: Interfacial adaptation *in vivo* in Class II cavities *American Journal of Dentistry* **11(4)** 165-172.

©Operative Dentistry, 2002, **27**, 381-386

Surface Texture of Resin-Modified Glass Ionomer Cements: Effects of Finishing/Polishing Systems

AUJ Yap • WS Tan • JC Yeo
WY Yap • SB Ong

Clinical Relevance

Depending on the finishing technique, surface roughness of resin-modified glass ionomer cements may differ in the vertical and horizontal axis. CompoSite points are recommended for finishing/polishing of resin-modified glass ionomer cements where graded abrasive disk systems cannot be used.

SUMMARY

This study investigated the surface texture of two resin-modified glass ionomer cements (RMGICs) in the vertical and horizontal axis after treatment with different finishing/polishing systems. Class V preparations were made on the buccal and lingual/palatal surfaces of freshly extracted teeth. The cavities on each tooth were restored with Fuji II LC (GC) and Photac-Fil Quick (ESPE) according to manufacturers' instructions. Immediately after light-polymerization, gross finishing was done with 8-flute tungsten carbide burs. The teeth were then randomly divided into four groups and finished/polished with (a) Robot Carbides (RC); (b) Super-Snap system (SS); (c) OneGloss (OG) and (d) CompoSite Points (CS). The sample size for each material-finishing/polishing system combination was eight. The mean surface roughness (µm) in vertical (RaV) and horizontal (RaH) axis was measured using a profilometer. Data was subjected to ANOVA/Scheffe's tests and Independent Samples t-test at significance level 0.05. Mean RaV ranged from 0.59-1.31 and 0.83-1.52, while mean RaH ranged from 0.80-1.43 and 0.85-1.58 for Fuji II LC and Photac-Fil, respectively. Results of statistical analysis were as follows: Fuji II LC: RaV-RC, SS<OG & SS<CS; RaH-SS, CS<RC, OG; Photac-Fil: RaV- SS, CS<OG; RaH-SS<RC, OG & CS<RC (where < indicates significantly greater Ra values). Significant differences in RaV and RaH values were observed when Fuji II LC was finished with RC. The use of carbides (RC) and one-step rubber abrasive system (OG) for finishing/polishing of RMGICs is not recommended. Graded abrasive disk (SS) or two-step rubber abrasive (CS) systems should be used instead.

*Adrian UJ Yap, BDS, MSc, PhD, FAMS, FADM, FRSH, associate professor, Department of Restorative Dentistry, Faculty of Dentistry, National University of Singapore

WS Tan, student, Faculty of Dentistry, National University of Singapore

JC Yeo, student, Faculty of Dentistry, National University of Singapore

WY Yap, student, Faculty of Dentistry, National University of Singapore

SB Ong, student, Faculty of Dentistry, National University of Singapore

*Reprint request: 5 Lower Kent Ridge Road, Singapore 119074, Republic of Singapore; e-mail: rsdyapuj@nus.edu.sg

INTRODUCTION

Glass ionomer cements consist of a basic glass and an acidic polymer and are set by an acid-base reaction between these components. As restorative materials, glass ionomer cements have numerous desirable properties including fluoride release, adhesion to dentin and enamel, similar thermal expansion to dentin and low solubility in oral fluids when set. Resin-modified glass ionomer cements were introduced to help overcome moisture sensitivity and low early mechanical strength associated with conventional glass ionomer cements while maintaining their clinical advantages (Sidhu & Watson, 1995). The effect of finishing and polishing on surface roughness of materials is an important consideration in the restorative process. This is especially true of cervical restorations where poorly finished or polished restorations can lead to plaque retention resulting in periodontal problems and recurrent caries. In addition, rough surfaces also contribute to staining (Shintani & others, 1985; Dunkin & Chambers, 1983; Chan, Fuller & Hormati, 1980; Weitman & Eames, 1975; Larato, 1972). High quality finishing and polishing can therefore improve the aesthetics and longevity of direct tooth-colored restorations including resin-modified glass ionomer cements. Finishing refers to the gross contouring or reduction of the restoration to the desired anatomy, while polishing refers to reduction of the roughness and scratches caused by finishing instruments. Although restoratives that are cured against a matrix are not devoid of surface imperfections, they represent the smoothest surface possible (Yap, Lye & Sau, 1997). However, despite careful placement of matrixes, removing excess material or recontouring restorations is often clinically necessary. This requires some degree of finishing and polishing that will violate the smoothness obtained with a matrix.

In general, finishing and polishing sequences similar to those recommended for composites and conventional glass ionomer cements have been suggested for resin-modified glass ionomer cements. The instruments commonly used include carbide burs (8 to 30-fluted), 25-50 µm diamonds, abrasive-impregnated rubber cups and points, abrasive disks, abrasive strips and polishing paste. Numerous studies on the finishing and polishing of composite and conventional glass ionomer restoratives have been reported in the literature (Setcos, Tarim & Suzuki, 1999; Yap, Sau & Lye, 1998; Bouvier, Duprez & Lissac, 1997; Paulillo & others, 1997; Jefferies, Barkmeier & Gwinnett, 1992; Pearson, 1991). However, less is known about the finishing/polishing of resin-modified glass ionomer materials. Recent studies have not provided a consensus regarding the relative effectiveness of various finishing and polishing techniques when used in the clinical situation (Wilder & others, 2000; Hoelscher & others, 1998; Hondrum & Fernandez, 1997; Yap & others, 1997; Tate & Powers, 1996; St Germain & Meiers, 1996). The aforementioned studies were conducted using specimens made from materials placed in acrylic, stainless steel, macor or plexiglass molds and disks/blocks of material that may not be clinically relevant. In addition, none had addressed the consequence of bur orientation on surface roughness.

This study evaluated the effects of different finishing/polishing techniques on the surface texture of two resin-modified glass ionomer cements based on a tooth model. Differences in surface roughness in the vertical and horizontal axis resulting from bur orientation were also investigated.

METHODS AND MATERIALS

Table 1 shows the resin-modified glass ionomer cements investigated and their technical profiles. Thirty-two freshly extracted, non-carious premolars were selected for this study. The teeth were disinfected with 2% formalin-saline, cleaned and stored in distilled water at 4ºC until use. The apical third of the root(s) of each tooth were embedded in square acrylic

Table 1: *The Resin-Modified Glass Ionomer Cements Investigated*

Material	Manufacturer	Components	Mean Particle Size (µm)	Lot #
Fuji II LC	GC Corporation, Tokyo, Japan	*Powder:* Alumino silicate glass, pigments *Liquid:* Polyacrylic acid, distilled water, HEMA (17%), dimethacrylate monomer, camphoroquinone	4.5	9912202
Photac-Fil Quick	ESPE Dental Seefeld, Germany	*Powder:* Calcium aluminum fluorosilicate glass, copolymers of acrylic and maleic acids, tartaric acid, activator, pigments *Liquid:* HEMA (40%), difunctional monomer, water, camphoroquinone	7.0	0065231

Table 2: *Finishing/Polishing Systems and Sequences*

Product	Usage	Handpiece Speed	Manufacturer
Robot Carbide			
SH134F	Wet, 12 strokes	300,000 rpm	Shofu Inc,
SH134UF	Wet, 12 strokes	300,000 rpm	Kyoto, Japan
Super-Snap			
Coarse	Dry, 6 strokes	12, 000 rpm	Shofu Inc,
Medium	Dry, 6 strokes	12, 000 rpm	Kyoto, Japan
Fine	Dry, 6 strokes	12, 000 rpm	
Extra Fine	Dry, 6 strokes		
OneGloss	Wet, 12 heavy strokes	10, 000 rpm	Shofu Inc,
	Wet, 12 light strokes	10, 000 rpm	Kyoto, Japan
CompoSite Polishers			
CompoSite	Wet, 12 strokes	12,000 rpm	Shofu Inc,
CompoSite Fine	Dry, 12 strokes	12,000 rpm	Kyoto, Japan

Table 3: *Mean Surface Roughness for the Different Finishing/Polishing Systems*

Product	Materials	Mean Ra (µm)	
		RaV	RaH
Robot Carbide	**Fuji II LC**	0.93 (0.30)	1.43 (0.26)
	Photac-Fil Quick	1.28 (0.38)	1.58 (0.33)
Super-Snap	**Fuji II LC**	0.59 (0.16)	0.80 (0.29)
	Photac-Fil Quick	0.92 (0.22)	0.85 (0.17)
OneGloss	**Fuji II LC**	1.31 (0.19)	1.23 (0.15)
	Photac-Fil Quick	1.52 (0.32)	1.41 (0.26)
CompoSite Polishers	**Fuji II LC**	1.00 (0.32)	0.80 (0.22)
	Photac-Fil Quick	0.83 (0.36)	1.13 (0.28)

Standard deviations in parenthesis.

Table 4: *Comparison Between Finishing/Polishing Systems*

Ra	Materials	Differences
Vertical	**Fuji II LC**	Robot Carbide, Super-Snap < OneGloss Super-Snap < CompoSite
(RaV)	**Photac-Fil Quick**	Super-Snap, CompoSite < OneGloss
Horizontal	**Fuji II LC**	Super-Snap, CompoSite < Robot Carbide, OneGloss
(RaH)	**Photac-Fil Quick**	Super-Snap < Robot Carbide, OneGloss CompoSite < Robot Carbide

< indicates statistically significant difference. Results of one-way ANOVA/Scheffe's test (p<0.05).

blocks of approximately 10 mm length, breath and height. These acrylic blocks were used to fasten restored tooth specimens to the precision vice of the profiling instrument during roughness measurements. Wedge-shaped Class V preparations (approximately 4 mm wide (mesio-distally), 3-mm long (occluso-gingivally) and 2-mm deep were made on the buccal and lingual/palatal surfaces each tooth. The cavities on each tooth were restored with capsulated Fuji II LC (GC) and Photac-Fil Quick (ESPE). Cavities to be restored with Fuji II LC were first treated with Cavity Conditioner (GC) for 10 seconds, while cavities to be restored with Photac-Fil were treated with Ketac Conditioner (ESPE) for 10 seconds. The cavities were then washed for 30 seconds and gently air dried. The resin-modified glass ionomer cements were mixed according to manufacturers' instructions and injected into the cavities. Transparent preformed cervical matrixes (Hawe-Neos Dental, Bioggio, Switzerland) were placed over the filled cavities and pressure was applied to extrude excess material, which was subsequently removed. The cements were then light polymerized for 20 seconds using a curing light (Spectrum; Dentsply Inc, Milford, DE 19963, USA) with an output intensity ≥ 420 mW/cm², as assessed with a curing radiometer (Cure Rite, EFOS Inc, Ontario, Canada).

Immediately after light-polymerization, the cervical matrixes were removed and gross finishing was done with 8-flute tungsten carbide burs (Robot Carbide SH134; Shofu, Kyoto, Japan). Gross finishing was done in one direction under water spray using a high-speed handpiece at 300,000 rpm. The burs were replaced after gross finishing of every eight restorations. The restored teeth were then randomly divided into four groups and finished/polished with: (a) Robot Carbides (RC); (b) Super-Snap system (SS); (c) OneGloss (OG); and (d) CompoSite Polishers (CS). Table 2 reflects details of the finishing/polishing sequences. The sample size for each material-finishing/polishing system combination was eight. The specimens were washed and the mean surface roughness (µm) in vertical (RaV) (that is, along the long-axis of the tooth) and horizontal (RaH) axis (that is, mesio-distally) was measured using a profilometer (Surftest SV-400; Mitutoyo, Kanagawa, Japan). Readings were taken at the center of each restoration. Four sampling lengths of 0.25 mm were used giving a total evaluation of 1 mm. The profilometer was accurate to 0.01 µm. All statistical analysis was carried out at significance level 0.05. Multiple ANOVA was used to determine significant interactions between the various

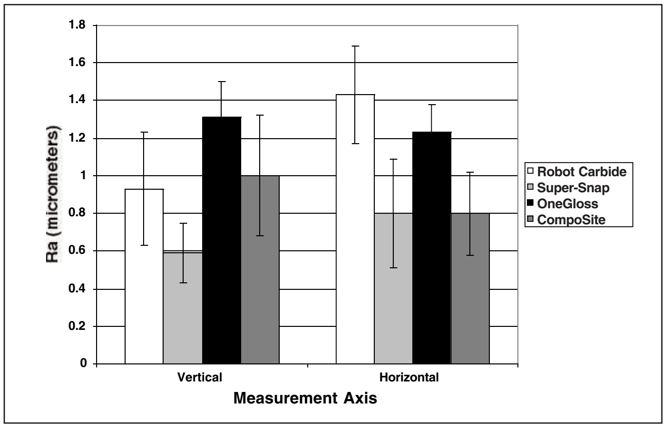


Figure 1. *Mean surface roughness of Fuji II LC after treatment with the different finishing/polishing systems.*

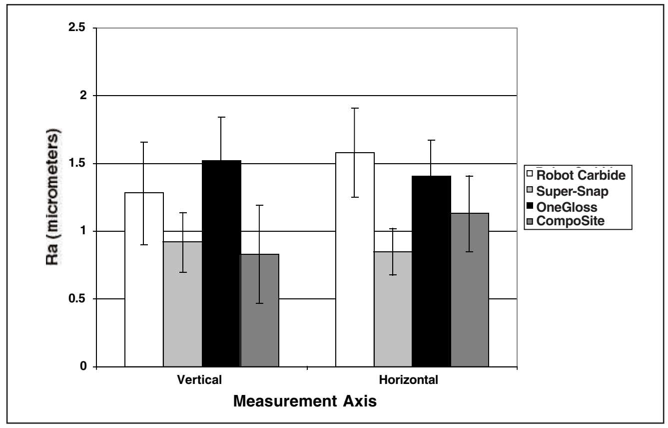


Figure 2. *Mean surface roughness of Photac-Fil Quick after treatment with the different finishing/polishing systems.*

Table 5: *Comparison Between Materials and Measurement Axis*

Comparison Between Materials		
Product	RaV	RaH
Robot Carbide	NS	NS
Super-Snap	Fuji II LC < Photac-Fil	NS
One Gloss	NS	NS
CompoSite	NS	Fuji II LC < Photac-Fil
Comparison Between Measurement Axis		
Products	Fuji II LC	Photac-Fil Quick
Robot Carbide	NS	RaV < RaH
Super-Snap	NS	NS
One Gloss	NS	NS
CompoSite	NS	NS

NS indicates no statistically significant difference while < indicates statistically significant differences. Results of independent samples t-tests (p.0.05)

independent variables. One-way ANOVA and Scheffe's post-hoc tests were used to compare the surface roughness obtained with the different finishing/polishing systems, while independent samples *t*-tests was employed to evaluate differences between materials and evaluation axis.

RESULTS

Table 3 and Figures 1 and 2 show the mean surface roughness obtained with the different finishing/polishing systems. Results of statistical analysis are shown in Table 4 and 5.

Mean RaV ranged from 0.59-1.31, while mean RaH ranged from 0.80-1.43 for Fuji II LC. Values obtained with Photac-Fil were somewhat higher and ranged from 0.83-1.52 for RaV and 0.85-1.58 for RaH. The smoothest surfaces were generally obtained with Super-Snap (Figures 1 and 2). MANOVA revealed significant interactions between materials, finishing/polishing system and measurement axis. For Fuji II LC, RaV values obtained for Robot Carbide and Super-Snap were significantly lower than for OneGloss. In addition, the RaV values for Super-Snap were also significantly lower than for CompoSite. In the horizontal axis, surfaces treated with Super-Snap and CompoSite were significantly smoother than those treated with Robot Carbide and OneGloss. For Photac-Fil, RaV values observed with Super-Snap and CompoSite were significantly lower than values observed with OneGloss. RaH values obtained with Super-Snap were significantly lower than values obtained with Robot Carbide and OneGloss. RaH values for CompoSite was also significantly lower than for Robot Carbide (Table 4). No significant difference in surface roughness was observed between Fuji II LC and Photac-Fil except for vertical measurements after treatment with Super-Snap and horizontal measurements after treatment with CompoSite. Significant difference in RaV and RaH was observed for Photac-Fil only after treatment with Robot Carbides (Table 5).

DISCUSSION

Finishing and polishing of resin-modified glass ionomer cements are complicated by the heterogeneous nature of these materials. The set materials can be considered biphasic in nature and consist of unreacted glass particles embedded in a polysalt/resin matrix. During finishing and polishing, the softer matrix phase is preferentially abraded, leaving the harder unreacted glass particles protruding from the surface. Materials with larger mean particle sizes are therefore expected to be rougher after finishing/polishing. The latter may account for the generally higher Ra values of Photac-Fil compared to Fuji II LC in both vertical and horizontal axis after treatment with the various finishing/polishing systems. To standardize the different aspects of the methodology, strict adherence to manufacturers' instructions were observed and the total number of strokes for each finishing/polishing system (24 strokes) and operator were kept constant.

Most, if not all, studies analyzing the effects of finishing/polishing systems on surface roughness of tooth-colored restoratives were conducted in only one axis. However, the effects of finishing/polishing systems on surface roughness were found to be material and direction dependent in this study. For both materials, using graded abrasive discs (Super-Snap) generally provided the best surface finish. Results concur with previous studies that investigated the surface finish of resin-modified glass ionomer cements (Hoelscher & others, 1998; Hondrum & Fernandez, 1997; Yap & others, 1997; St Germain & Meiers, 1996). It is important to note that disorderly application of different grits of Super-Snap instead of descending order could markedly reduce smoothness of the polished surface (Kanter, Koski & Bogdan, 1983). With the exception of RaV for Fuji II LC, no significant difference in surface roughness was observed between treatment with Super-Snap and CompoSite Polishers. CompoSite Polishers are therefore a viable alternative for finishing/polishing resin-modified glass ionomer cements where abrasive disks cannot be used. Clinically, the use of abrasive disks for polishing of cervical restorations is contraindicated when restoration margins are at the gingival crest or subgingival, as it may result in severe gingival trauma. The CompoSite polishing system is a two-step rubber abrasive system. The abrasive used in the CompoSite Polisher is aluminum oxide (approximately 40 µm), while that used in the CompoSite Fine Polisher is zirconium (approximately 20 µm). The use of this system for finishing/polishing of resin-modified glass ionomer cements has not been reported in the literature.

For both resin-modified glass ionomer cements, the roughest surface was observed after treatment with OneGloss in the vertical axis and with Robot Carbides in the horizontal axis. OneGloss is a one-step rubber abrasive finishing/polishing system. Heavy pressure (approximately 100 g) is applied for finishing, while feather light pressure (approximately 30 g) is used for polishing. The system is somewhat similar to the Enhance Finishing/Polishing System (LD Caulk/Dentsply, Milford, DE 19963, USA) evaluated in most previous studies (Hoelscher & others, 1998; Hondrum & Fernandez, 1997; Yap & others, 1997; Tate & Powers, 1996). These studies generally showed that Enhance is more effective on composites than on resin-modified glass ionomer cements. Significant difference in RaV between Robot Carbide and OneGloss for Fuji II LC may be attributed to the orientation of flutes on the carbide burs. The Robot Carbide system is a three-step finishing system. The 8-fluted bur was used for gross finishing of all restorations. This was followed by treatment with 16- (SH134F) and 30-fluted (SH134 UF) burs, respectively. The cutting edge of the flutes was along the long-axis (that is, vertical axis) of the burs. Disruption to the surface of materials is therefore expected to be less in the vertical than in the horizontal axis. The aforementioned also accounts for the significantly poorer surface finish of Robot Carbides as compared to Super-Snap and CompoSite Polishers in the horizontal axis. This finding agrees with St Germain & Meiers (1996). They found that the use of carbide burs alone produced the highest Ra values for resin-modified glass ionomer cements. The Ra values in their study were taken perpendicular to the finishing direction (horizontal axis) and not parallel. A dual axis approach, such as that adopted by the current study, may therefore be more discriminatory in the evaluation of finishing/polishing systems. The lack of statistical significance in RaV between Robot Carbide and OneGloss for Photac-Fil may be accounted for by the larger mean particle size and hence greater surface roughness after finishing and polishing.

Differences in RaV and RaH measurements varied between finishing/polishing systems and materials. Significant differences in RaV and RaH values was, however, only observed for Photac-Fil when treated with carbide burs. This finding could be attributed to both orientation of the bur flutes and the large mean particle size (7 µm) of Photac-Fil. As mentioned earlier, surface disruption with carbide burs is expected to be greater in the horizontal axis. This effect may be amplified by abrasion of the relatively larger glass fillers during finishing. In view of the significant disparity between mean glass particle size, significant difference in Ra values should be observed between Fuji II LC and Photac-Fil for all finishing/polishing systems. Significant difference in RaV and RaH values were, however, only observed after finishing/polishing with Super-Snap and CompoSite polishers, respectively. The lack of statistical significance after treatment with Robot Carbide and OneGloss could be accounted for by the poorer surface texture obtained with these systems. Horizontal (mesio-distal) movement of Super-Snap during finishing/polishing may increase the surface roughness of Fuji II LC, resulting in similar RaH values to Photac-Fil. The lack of statistical significance for RaV between cements could be partially attributed to the poorer surface finish of Fuji II LC with CompoSite in the vertical axis.

CONCLUSIONS

Under the conditions of this in-vitro study:

1. The effects of finishing/polishing systems on the surface roughness of resin-modified glass ionomer cements are material and axis dependent.

2. The smoothest surfaces were generally obtained with the graded abrasive disk system (Super-Snap).

3. Treatment with the two-step rubber abrasive system (CompoSite) resulted in comparable surface finish to the graded abrasive disk system.

4. Treatment with the one-step rubber abrasive system (OneGloss) produced the largest Ra values in the vertical axis.

5. Treatment with the carbide finishing system (Robot Carbides) produced the largest Ra values in the horizontal axis.

(Received 21 September 2001)

References

Bouvier D, Duprez JP & Lissac M (1997) Comparative evaluation of polishing systems on the surface of three aesthetic materials *Journal of Oral Rehabilitation* **24(12)** 888-894.

Chan KC, Fuller JL & Hormati AA (1980) The ability of foods to stain two composite resins *Journal of Prosthetic Dentistry* **43(5)** 542-545.

Dunkin RT & Chambers DW (1983) Gingival response to Class V composite resin restorations *Journal of the American Dental Association* **106(4)** 482-484.

Hoelscher DC, Neme AM, Pink FE & Hughes PJ (1998) The effect of three finishing systems on four esthetic restorative materials *Operative Dentistry* **23(1)** 36-42.

Hondrum SO & Fernandez R Jr (1997) Contouring, finishing, and polishing Class 5 restorative materials *Operative Dentistry* **22(1)** 30-36.

Jefferies SR, Barkmeier WW & Gwinnett AJ (1992) Three composite finishing systems: A multisite *in vitro* evaluation *Journal of Esthetic Dentistry* **4(6)** 181-185.

Kanter J, Koski RE & Bogdan MS (1983) How to achieve the best surface polish on composite resins *Canadian Dental Association Journal* **11(1)** 40-44

Larato DC (1972) Influence of a composite resin restoration on the gingiva *Journal of Prosthetic Dentistry* **28(4)** 402-404.

Paulillo LA, Coradazzi JL, Lovadino JR & Serra MC (1997) Surface finishing of glass ionomer *American Journal of Dentistry* **10(3)** 137-140.

Pearson GJ (1991) Finishing of glass-ionomer cements *Dental Update* **18(10)** 424-428.

Sectos JC, Tarim B & Suzuki S (1999) Surface finish produced on resin composites by new polishing systems *Quintessence International* **30(3)** 169-173.

Sidhu SK & Watson TF (1995) Resin-modified glass ionomer materials. A status report for the American Journal of Dentistry *American Journal of Dentistry* **8(1)** 59-67.

Shintani H, Satou J, Satou N, Hayashihara H & Inoue T (1985) Effects of various finishing methods on staining and accumulation of Streptococcus mutans HS-6 on composite resins *Dental Materials* **1(6)** 225-227.

St Germain HA, Meiers JC (1996) Surface roughness of light-activated glass-ionomer cement restorative materials after finishing *Operative Dentistry* **21(3)** 103-109.

Tate WH & Powers JM (1997) Surface roughness of composites and hybrid ionomers *Operative Dentistry* **21(2)** 53-56.

Weitman RT & Eames WB (1975) Plaque accumulation on composite surfaces after various finishing procedures *Journal of the American Dental Association* **91(1)** 101-106.

Wilder AD Jr, Swift EJ Jr, May KN Jr, Thompson JY & McDougal RA (2000) Effect of finishing technique on the microleakage and surface texture of resin-modified glass ionomer restorative materials *Dental Materials* **28(5)** 367-373.

Yap AU, Lye KW & Sau CW (1997). Surface characteristics of tooth-colored restoratives polished utilizing different polishing systems *Operative Dentistry* **22(6)** 260-265.

Yap AU, Sau CW & Lye KW (1998) Effects of finishing/polishing time on surface characteristics of tooth-coloured restoratives *Journal of Oral Rehabilitation* **25(6)** 456-461.

©Operative Dentistry, 2002, **27,** 387-395

Nanoleakage of Dentin Adhesive Systems Bonded to Carisolv-Treated Dentin

S Kubo • H Li
MF Burrow • MJ Tyas

Clinical Relevance

Nanoleakage patterns of caries-affected dentin are different from those of normal dentin. This may influence the success of the bond of resin-based composite restorations and possibly clinical longevity.

SUMMARY

The hybrid layer created in caries-affected dentin has not been fully elucidated and may influence bond durability. This study investigated the nanoleakage patterns of caries-affected dentin after excavation with Carisolv or conventional instruments treated with one of three adhesive systems. Flat occlusal dentin surfaces, including carious lesions, were prepared from extracted human molars and finished with wet 600-grit silicon carbide paper. Carious dentin was removed with Carisolv or round steel burs in conjunction with Caries Detector. PermaQuik, Single Bond or One-Up Bond F was bonded to the excavated dentin surfaces and adjacent flat occlusal surfaces and it was covered with Silux Plus resin-based composite. After 24-hour storage in 37°C water, the bonded interfaces were polished to remove flash, and the surrounding tooth surfaces were coated with nail varnish. Specimens were immersed in 50% (w/v) silver nitrate solution for 24 hours, exposed to photo developing solution for eight hours, then sectioned longitudinally through the bonded, excavated dentin or "normal" dentin surfaces. The sectioned surfaces were polished, carbon coated and observed in a Field Emission-SEM using back scattered electrons. Silver deposition occurred along the base of the hybrid layer for all specimens. However, Single Bond showed a greater density of silver deposition in the caries-affected dentin compared with normal dentin. PermaQuik had a thicker hybrid layer in caries-affected dentin than normal dentin. One-Up Bond F exhibited a thin hybrid layer in normal dentin, but the hybrid layer was often difficult to detect in caries-affected dentin.

*Shisei Kubo, DDS, PhD, associate professor, Nagasaki University School of Dentistry

Heping Li, DDS, graduate student, School of Dental Science, The University of Melbourne

Michael F Burrow, MDS, PhD, associate professor, School of Dental Science, The University of Melbourne

Martin J Tyas, BDS, PhD, DDSc, associate professor and Reader, School of Dental Science, The University of Melbourne

*Reprint request: Department of Endodontics and Operative Dentistry, Nagasaki University School of Dentistry, 1-7-1, Sakamoto, Nagasaki 852-8588, Japan; e-mail: kubo@net.nagasaki-u.ac.jp

INTRODUCTION

Improved formulations of dentin adhesives and mechanical properties of resin-based composite have enhanced the longevity of resin-based composite restorations (Van Meerbeek & others, 1994). The rate of development of adhesive systems is often too rapid to evaluate the clinical performance of new products, and a great deal of effort has been made to develop adhesive systems that have durable bonds to tooth substances. As a result, laboratory tests need to predict the long-term clinical performance of restorative systems as accurately as possible. Although the most clinically relevant bonding substrates are caries-affected or cervical sclerotic dentin, most bonding and microleakage tests have been conducted using normal dentin. Bonding to the other substrates is difficult due to the limitations of the variability and size of the carious lesion. However, the development of the microtensile bond test has made it possible to determine the bond strength of adhesive systems to caries-affected and sclerotic cervical dentin, since the test uses a very small specimen (Sano & others, 1994; Phrukkanon, Burrow & Tyas, 1998). Studies using this method have revealed that many adhesive systems produce lower bond strengths to caries-affected dentin compared with normal dentin (Nakajima & others, 1995, 1999, 2000; Yoshiyama & others, 2000). In addition, the thickness of the hybrid layer created in caries-affected dentin was greater than in normal dentin (Nakajima & others, 1999, 2000).

Carious dentin is usually removed with a slow-speed handpiece, but the non-specific nature of excavation may result in excessive loss of tissue, thus affecting the prognosis of the treated tooth. The recently developed chemo-mechanical caries removal solution, Carisolv (MediTeam, Sävedalen, Sweden), is less traumatic and a good alternative to conventional rotary instruments (Beeley, Yip & Stevenson, 2000). Carisolv consists of a pink gel containing sodium hypochlorite solution and three amino acids—lysine, leucine and glutamic acid, together with carboxymethylcellulose as a thickener. The gel is applied to the carious lesion and after 30 seconds the carious dentin can be removed with specially designed hand instruments. Carious dentin may not be completely removed with the solution (Cederlund, Lindskog & Blomlöf, 1999) but has some potential for dissolving denatured dentin (Hannig, 1999).

Current adhesive systems are generally divided into four broad types. The first type, often termed "conventional systems," consists of a demineralizing agent, typically phosphoric acid, a primer and an adhesive resin. The second type is the "single-bottle" materials that typically have a demineralizing agent, such as phosphoric acid and a combined primer and adhesive resin. The third type is termed "self-etching primer systems," which combine the demineralizing agent and primer with a separate adhesive resin. These systems have relatively high bond strengths to enamel and dentin (Perdigão & others, 1999; Kubo & others, 2000, 2001), and the latter two have been designed to simplify clinical procedures. The most recent fourth type combines all components into the liquid and has been referred to as "all-in-one" systems.

Complete penetration of resin monomers into demineralized dentin is essential for creating strong adhesion and a good seal regardless of the adhesive system (Nakabayashi, Kojima & Masuhara, 1982; Eick & others, 1997). However, the ideal penetration of resin monomers into demineralized dentin may not always be achieved due to residual water around collagen fibrils, collapse of the collagen network, incomplete resin infiltration and polymerization (Sano & others, 1995; Eick & others, 1997). A micro-Raman spectroscopic study revealed a transition of resin concentration in demineralized superficial dentin, with the greatest levels of resins being located close to the etched dentin surface (Van Meerbeek & others, 1993). Sano & others (1995) have demonstrated the presence of leakage through nanometer-sized spaces and porosity within the hybrid layer or demineralized dentin. This phenomenon has been termed "nanoleakage." These findings have raised concerns about the long-term stability of the collagen and resin in the hybrid layer with respect to hydrolysis.

Organic substances and the presence of acid-resistant mineral deposits in caries-affected dentin may interfere with uniform resin permeation or conversion of adhesive monomers to a polymeric network (Nakajima & others, 1995; Yoshiyama & others, 2000). The hybrid layer created in caries-affected dentin has not been fully elucidated and may have an influence on bond durability.

This study investigated the nanoleakage patterns of caries-affected dentin after treatment with rotary instruments or Carisolv gel and various adhesive systems: PermaQuik (Ultradent, South Jordan, UT 84095, USA), a conventional three-step system; Single Bond (3M Dental Products, St Paul, MN 55144, USA), a single-bottle system and One-Up Bond F (Tokuyama Dental, Tokyo, Japan), an all-in-one self-etching-priming and bonding system. It was hypothesized that nanoleakage patterns would not differ between normal and caries-affected dentin and adhesive systems.

METHODS AND MATERIALS

Twenty-four molars with coronal dentin caries extending no further than half-way to the pulp were used; they were stored in physiological saline containing 0.1% thymol. Occlusal enamel was removed using a model trimmer under running water. The flat occlusal dentin surfaces, including carious lesions, were examined under a dissecting microscope at x20 magnification to ensure that no enamel remnants remained after they were wet-ground with 600-grit silicon carbide paper. Subsequently, the lingual or buccal surface was also ground to expose an area of the carious lesion on the surface (Figure 1). This surface was exposed to elucidate the nanoleakge pattern of the

Table 1: *Materials, Manufactures, Batch Numbers, Compositions and pH*

Adhesive Systems	Manufacturer	Components	Batch #	Chemical Composition	pH of Conditioners
PermaQuik	Ultradent Products, South Jordan, UT USA	Ultra-Etch Bonding Primer		35% phosphoric acid, silica Canadian balsam, methacrylic acid, HEMA, phosphate monomer, ethanol, CQ	0.02
		Bonding Resin		Bis-GMA, TEGDMA, tertiary amine, CQ, 40% filler with fluoride, diluent monomer	
Single Bond	3M Dental Products, Division, St Paul, MN USA	Etchant Adhesive	7EL 7AR	35% phosphoric acid Bis-GMA, HEMA, dimethacrylates polyalkenoic acid copolymer, water, ethanol, PI	0.6
One-Up Bond F	Tokuyama, Dental, Tokyo Japan	Bonding Agent A	451029	MAC-10, methacryloyloxyalkyl acid phosphate multi-functional methacrylic monomers, PI	1.8
		Bonding Agent B	451029	HEMA, water, fluoroaluminosilicate glass fillers, PI	
Caries Detector	Kuraray Medical Inc. Kurashiki, Japan		0250D	1.0 % acid red, propylene glycol	6.5
Carisolv	MediTeam, Göteborg, Sävedalen, Sweden	Red Gel	906G2411	0.1M glutamic acid/leucine/lysine, water sodium chloride, sodium hydroxide, erythrocin	11
		Transparent Gel	906G2411	0.5% sodium hypochlorite	

(HEMA = 2-hydroxyethyl methacrylate; CQ = camphorquinone; Bis-GMA = bisphenyl glycidyl methacrylate; TEGDMA = triethylene glycol dimethacrylate; PI = photo initiator; MAC-10 = 11methacryloxy-1,1-undecanedicarboxylic acid)

Table 2: *Bonding Procedures*

Materials	Steps	Procedures
PermaQuik	Step 1	Apply Ultra-Etch for 15 seconds, rinse for 5 seconds, gently air dry
	Step 2	Rub Bonding Primer firmly for 15 seconds, air-thin for 1-3 seconds, air-dry for 10 seconds, light-cure for 20 seconds
	Step 3	Rub Bonding Resin with moderate pressure for 15 seconds, gently air thin, light-cure for 20 seconds
Single Bond	Step 1	Apply Etchant for 15 seconds, rinse for 10 seconds, gently air dry
	Step 2	Brush two consecutive coats of Adhesive, gently air dry for 2-5 seconds, light-cure for 10 seconds
One-Up Bond F	Step 1	Apply a mixture of Bonding Agent A and B for 20 seconds, gently air-blow, light-cure for 10 seconds

treated carious lesions. The teeth were randomly divided into two groups; one group was subject to conventional caries removal using steel burs in conjunction with a caries-detector dye (Caries Detector, Kuraray Medical Inc, Kurashiki, Japan) and the other group was used for caries removal with Carisolv.

Caries Detector Group: The carious dentin was removed with round steel burs at low speed guided by Caries Detector as described by Fusayama (1993). A drop of Caries Detector was applied to the carious lesion for 10 seconds and washed with water. Any red-stained carious dentin was carefully removed with round burs matched to the size of the stained area. This procedure was repeated until the excavated dentin surface stained light pink or did not stain at all. The excavated margins were then finished with a small round bur.

Carisolv Group: The carious dentin was removed by Carisolv treatment following the manufacturer's instructions. A drop of the mixed Carisolv gel was applied to the carious dentin and left *in situ* for at least 30 seconds. The softened carious dentin was then removed by careful excavation with non-cutting Carisolv hand instruments. This procedure was repeated until the Carisolv gel was no longer cloudy and the dentin surface felt hard when probed with a sharp dental probe. Finally, the periphery of the excavated margins was finished with hand instruments or round steel burs.

The teeth for each group were allocated to the three bonding subgroups (Table 1). The region of excavated dentin and the surrounding flat occlusal normal dentin surfaces were bonded with one of the bonding systems

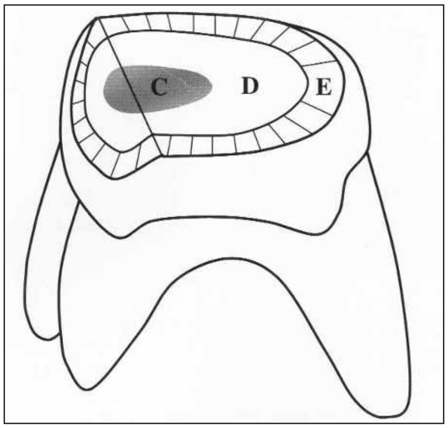


Figure 1. *Illustration of a specimen with coronal carious dentin. E = ground enamel, D = ground dentin, C = carious lesion. The flat occlusal dentin surface, including carious lesions, was prepared and wet-ground with 600-grit silicon carbide paper. The lingual or buccal surface was exposed to elucidate the nanoleakge pattern of the treated carious lesions.*

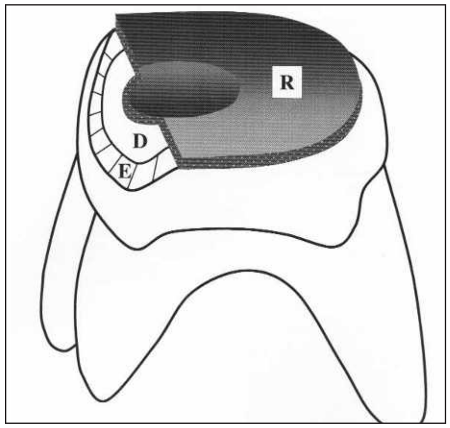


Figure 2. *Illustration of a bonded specimen. E = ground enamel, D = ground dentin, R = resin-based composite. The excavated dentin and surrounding flat occlusal surfaces (normal dentin and enamel) were bonded with the adhesive system and covered with a 1-mm thick layer of resin-based composite.*

according to the manufacturer's instructions (Table 2). The excavated surface was covered with a 1-mm thick layer of resin-based composite (Silux Plus, 3M Dental Products), extended over the flat occlusal surface around the excavated dentin and light-cured for 40 seconds using a halogen lamp light curing unit (Visilux 2; 3M Dental Products) (Figure 2). After storage in tap water at 37°C for 24 hours, the margins on the buccal or lingual surfaces were finished and polished with Sof-Lex disks (3M Dental Products). The specimens were examined using a microscope at x20 magnification to ensure that no flash was left along the exposed dentin-composite interfaces.

The root apices of each tooth were sealed with Silux Plus, and the tooth was coated with nail varnish to within 1-2 mm of the bonded interface on the buccal or lingual surface. The teeth were placed in 50% (w/v) silver nitrate solution in total darkness for 24 hours, rinsed in running water for five minutes, immersed in photodeveloping solution and exposed to a fluorescent light for eight hours. The teeth were rinsed in water for five minutes and sectioned bucco-lingually across the bonded surface with a low-speed diamond saw under water spray. Three or four sections were made through the excavated and normal dentin regions of each tooth. At least six sections were prepared for each experimental group. All the sectioned surfaces were polished with increasingly fine diamond pastes (6, 3, 1 µm; Buehler Ltd, Lake Buff, IL 60044, USA).

The specimens were cleaned ultrasonically in water for 10 minutes, air dried and mounted on aluminum stubs, placed in a desiccator for 24 hours and coated with carbon. Examination for nanoleakage was carried out in a field-emission scanning electron microscope (FE-SEM, XL 30 FEG, Phillips, Eindhoven, The Netherlands) using backscattered electron mode at x2000 magnification.

RESULTS

PermaQuik created a very distinct hybrid layer between dentin and the adhesive resin regardless of the dentin substrate used (Figure 3). In the case of normal dentin, the hybrid layer was from 2-4 µm thick. Thin silver deposits at the base of the hybrid layer and loose silver deposits within the hybrid layer were observed. Dentinal tubules were slightly stained with silver and some contained filler particles of the adhesive resin. The hybrid layer created in caries-affected dentin was thicker than those created in normal dentin, and they ranged from 4-10 µm for the carious detector group and 4-8 µm for the Carisolv group. In the case of the Caries Detector group, there appeared to be no differences in nanoleakage patterns between normal dentin except for the thickness of the hybrid layer. In the case of the Carisolv group, the caries-affected dentin was stained slightly with silver. The dentin beneath the hybrid layer exhibited small cracks and porosities that may result from the specimen preparation. This is probably caries-affected dentin.

Single Bond produced a relatively distinct hybrid layer (Figure 4), from 2-5 µm thick. The silver deposition at the base of the hybrid layer created in caries-affected dentin was more extensive than in normal dentin. A thin line of silver was also observed at the top of the hybrid layer, and many patches of silver deposits existed within the hybrid layer. Occasionally, a relatively large mass stained with silver was observed on the hybrid layer or within the adhesive resin (Figure 4b). In addition, many amorphous structures were seen in the adhesive resin layer. There were few differences in the nanoleakage pattern between caries-affected and normal dentin, except for the intensity of silver deposits at the base of the hybrid layer, which was always greater in the caries-affected dentin.

One-Up Bond F created a thin hybrid layer in normal dentin, from 1-2 µm thick (Figure 5). In the case of normal dentin, silver deposits occurred at the base of the hybrid layer. In the case of caries-affected dentin, when detected, silver was deposited almost throughout the entire thickness of the hybrid layer. When a distinct hybrid layer was not formed, silver particles were precipitated at the interface between the caries-affected dentin and adhesive resin. In addition, loose silver deposits were frequently found in the porous caries-affected dentin. Occasionally, the caries-affected dentin

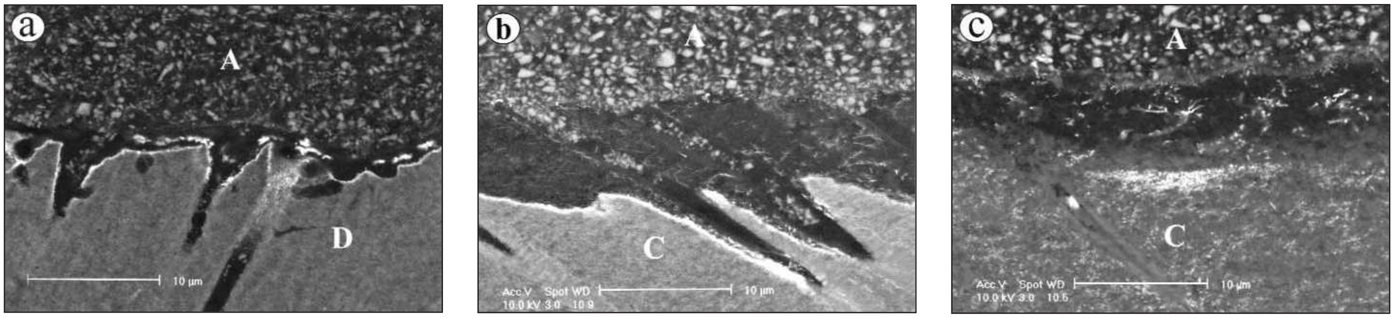


Figure 3. *Backscattered SEM images of the interface bonded with PermaQuik (x2000). (a) normal dentin; thin silver deposits at the base of the hybrid layer and loose silver deposits within the hybrid layer. Dentinal tubules were slightly stained by silver, and some were filled with filler particles of the adhesive resin. (b) caries-affected dentin with Caries Detector; showing a thicker hybrid layer. Filler particles can be seen in the dentinal tubules. (c) caries-affected dentin with Carisolv; the hybrid layer is thicker and many tubules are occluded. The dentin beneath the hybrid layer exhibited small cracks and porosities and was slightly stained with silver. (A, D and C represent adhesive resin, normal dentin and caries-affected dentin, respectively.)*

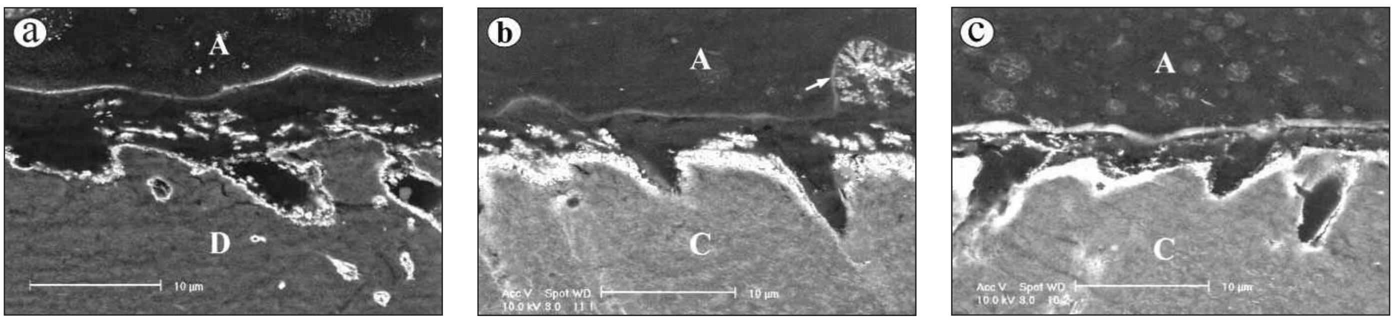


Figure 4. *Backscattered SEM images of the interface bonded with Single Bond (x2000). Silver deposits at the base of the hybrid layer, a thin line of silver at the top of the hybrid layer and many patches of silver within the hybrid layer can be observed. There were also many amorphous structures (lightly stained by silver) in the adhesive resin layer. (a) normal dentin. (b) caries-affected dentin with Caries Detector; dense silver deposits existed at the base of the hybrid layer. A relatively large mass stained by silver can be observed at the top of the hybrid layer (arrow). (c) caries-affected dentin with Carisolv; quite heavy deposits of silver can be seen at the base of the hybrid layer. (A, D and C represent adhesive resin, normal dentin and caries-affected dentin, respectively.)*

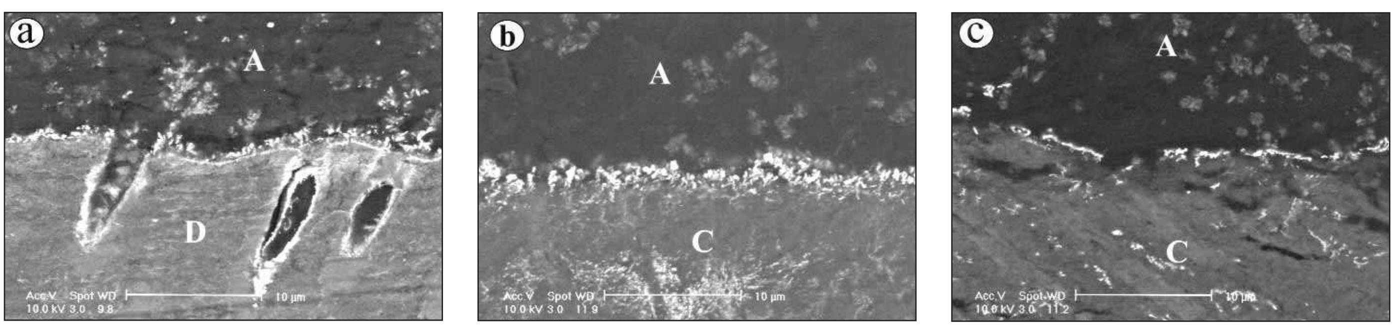


Figure 5. *Backscattered SEM images of the interface bonded with One-Up Bond F (x2000). (a) normal dentin; silver is deposited at the base of a thin hybrid layer. (b) caries-affected with Caries Detector; silver deposits can be observed throughout almost the entire thickness of the hybrid layer. Most dentinal tubules were occluded. (c) caries-affected dentin with Carisolv; silver is precipitated along the interface between dentin and the adhesive resin. A greater degree of cracking and porosity than the other specimens were noted and loose silver deposits can be observed within them. (A, D and C represent adhesive resin, normal dentin and caries-affected dentin, respectively.)*

prepared with the Carisolv system showed a greater degree of cracking and porosity than the other specimens. There were also many amorphous structures lightly stained by silver in the adhesive resin layer.

DISCUSSION

The methods described in this paper have been validated by previous work in the authors' laboratory (Li, Burrow & Tyas, 2000a). In particular, the pH of 3.4 of the silver nitrate solution has been shown not to influence the results (Li, Burrow & Tyas, submitted for publication).

Carious dentin has been reported to consist of two layers (Fusayama, 1993). The "outer carious dentin" is infected with bacteria, is unremineralizable, contains irreversibly denatured collagen and is non-vital and not sensitive. Whereas, the "inner carious dentin" is bacteria-free, remineralizable with reversibly denatured collagen, vital and sensitive, though it is partially demineralized and softer. During caries removal, the outer carious dentin should be completely removed, while much of the inner carious dentin should be preserved. Fusayama (1993) proposed using a dye solution (Caries Detector) that stains only the outer carious dentin as a guide to caries removal. Sano, 1987 advises that lightly pink-stained dentin should be preserved because bacterial invasion is not found in such dentin. Several studies have demonstrated that using Caries Detector is effective in leaving a substantial amount of caries-affected dentin (Harnirattisai & others, 1992; Nakajima & others, 1995, 1999, 2000; Yoshiyama & others, 2000). Carisolv excavation is also effective in the selective removal of infected dentin (Beeley & others, 2000). This has been confirmed by the use of natural autofluorescence (Banerjee & Boyde, 1998; Banerjee, Kidd & Watson, 2000).

Caries-affected dentin refers to the inner carious dentin that mostly consists of the so-called transparent layer (Fusayama, 1993). The lumen of the dentinal tubules in this zone contain crystals such as whitlockite, which are intermediate products due to the slow progress of caries. Caries-affected dentin has been reported to be less permeable than normal dentin due to the presence of these mineral deposits (Pashley & others, 1991; Fusayama, 1993). However, caries-affected dentin exhibits a lower hardness than normal dentin (Fusayama, 1993; Nakajima & others, 1995, 1999, 2000) probably because the apatite crystals of intertubular dentin in caries-affected dentin are markedly decreased in size and number due to demineralization (Fusayama, 1993). With regard to the acid-resistance of caries-affected dentin, there are no consistent findings. Caries-affected dentin includes acid-resistant crystals and extrinsic proteins that may have permeated into the mineral phase during the cyclic demineralization-remineralization caries process, which may result in greater resistance to acid etching (Yoshiyama & others, 2000). Nakajima & others (2000) have suggested that a stronger acid may be required in order to dissolve the mineral phase of caries-affected dentin in order to obtain sufficient resin infiltration for high resin bond strengths. Alternatively, caries-affected dentin has been suggested to be susceptible to the effect of acid treatment because the thickness of the hybrid layer created in caries-affected dentin is greater than that in normal dentin (Nakajima & others, 1999, 2000; Yoshiyama & others, 2000). The intertubular dentin of caries-affected dentin may be more porous since it is already partially demineralized.

Although the lengths of silver penetration were recorded under low (x40) and high (x1000) magnification as described by Li, Burrow & Tyas (2000b), the data could not be statistically analyzed, owing to the great variation in form and depth of the excavated surfaces. However, PermaQuik tended to show less nanoleakage than the other two adhesive systems used. PermaQuik is a conventional adhesive system and its primer contains camphorquinone (CQ). Miyazaki & others (1995) indicated that light irradiation of a dentin primer containing CQ was effective in improving wettability. Firmly rubbing the primer into the demineralized dentin may also allow its deeper penetration (Vargas, Cobb & Armstrong, 1997). These factors could possibly facilitate resin infiltration into acid-etched dentin.

Thicker hybrid layers were created in caries-affected dentin compared to normal dentin, which is consistent with the results of previous studies (Nakajima & others, 1999, 2000). Probably, the increase in thickness of the demineralized layer does not allow the adhesive resin to fully infiltrate to the base of the demineralized dentin (Eick & others, 1997; Prati & others, 1998). However, few differences appeared in the nanoleakage pattern between normal and caries-affected dentin, indicating that sufficient resin infiltration probably occurred for PermaQuik. The other two materials showed slightly greater silver deposition, indicating that greater problems may have been associated with the infiltration of resin into the moist caries-affected dentin.

Caries-affected dentin obtained after using Carisolv non-cutting hand instruments and Carisolv gel has shown a thicker demineralized layer than that obtained when rotary instruments with Caries Detector were used (Sakooloamarka & others, in press). However, in this study, the thickness of the hybrid layers were slightly greater in the Caries Detector group than in the Carisolv group. This may be due to the variety of teeth or carious lesions examined. Using Caries Detector may result in excessive removal of sound dentin since the dye staining is a function of the level of porosity rather than the presence/absence of carious tissue (Yip, Stevenson & Beeley, 1994). Carisolv treatment probably allows for preservation of most of the caries-affected dentin. The dentin appeared porous after using non-cutting hand instruments, indicating what is believed to be caries-affected dentin. Another possible explanation can be due to remnants of carious dentin, since Carisolv may not remove carious dentin completely (Cederlund & others, 1999). In the clinical situation, this region probably contains a significant amount of water, which may affect bonding of the more hydrophobic bonding systems. These two caries removal techniques have been shown to produce different dentin surfaces after acid treatment because the sodium hypochlorite in Carisolv gel (pH 11) may cause some change to the dentin, especially the collagen (Sakooloamarka & others, in press). This was evidenced by the dentin beneath the hybrid layer being slightly stained with silver and the presence of small cracks and porosities.

Single Bond is a single-bottle adhesive system. It has been reported that using a separate hydrophilic primer is not necessary to obtain good resin infiltration and high bond strengths if proper formulations that contain both hydrophilic and diffusion promoting monomers are utilized (Prati & others, 1998). Although Single Bond has consistently shown relatively high bond strengths, it has an inconsistent sealing performance at dentin margins (Cardoso & others, 1999). Li & others (2000b) also reported that single-bottle systems showed greater nanoleakage scores than conventional systems (for example, PermaQuik) due to not using a separate primer, which may affect the depth of infiltration of the adhesive resin. The characteristic nanoleakage patterns for Single Bond were silver uptake at the top of the hybrid layer and many patches of silver deposits within the hybrid layer. Occasionally, relatively large masses lightly stained with silver were observed at the top of the hybrid layer, which were thought to be the polyalkenoic acid copolymer of the Single Bond resin. Several studies have indicated that polyalkenoic acid may produce an amorphous electron-dense phase at the top of the hybrid layer (Van Meerbeek & others, 1996; Vargas, Cobb & Denehy, 1997; Perdigão & others, 2000; Li & others, 2000a). These silver deposits may be related to the presence of polyalkenoic salts or a very thin layer of damaged collagen fibers (Li & others, 2000a). Li & others (2000a) also speculated that the remnants of ethanol contained in Single Bond might have some effect on the curing of the resin and also contribute to the discontinuous patches of silver deposits.

Single Bond studies (Nakajima & others, 2000; Yoshiyama & others, 2000) have demonstrated an increase in the thickness of the hybrid layer created in caries-affected dentin compared with normal dentin, which was not confirmed in this study. A possible explanation may be that the exposed dentinal tubules after caries removal show a great variation in the pattern of tubule occlusion even within the same cavity floor (Harnirattisai & others, 1992). The extent of demineralization by acid conditioning, as well as impregnation of resin into the intertubular dentin, is probably related to the number of dentinal tubules per square millimeter and the degree of their closure and orientation (Harnirattisai & others, 1992; Yoshiyama & others, 1995; Prati & others, 2000). The type (young, old, sclerotic, caries-affected and normal) and site (superficial and deep) of the dentin have been reported to have an effect on the thickness of the hybrid layer (Harnirattisai & others, 1992; Yoshiyama & others, 1995, 1996; Prati & others, 1999). In addition, the type of caries (acute or chronic) may be associated with the thickness of the hybrid layer created, but this aspect has yet to be fully investigated.

Nakajima & others (2000) and Yoshiyama & others (2000) demonstrated that Single Bond created what they termed "poorer quality" hybrid layers in caries-affected dentin compared with normal dentin and exhibited significantly lower bond strengths. This was thought to be due to the increase in the thickness of the hybrid layer and organic substances in caries-affected dentin that may interfere with uniform resin permeation or with complete resin polymerization (Nakajima & others, 1995; Yoshiyama & others, 2000). This provides one reason for caries-affected dentin bonded with Single Bond showing relatively dense silver deposits at the base of the hybrid layer.

One-Up Bond F combines the etching, priming and bonding steps into one procedure. The so-called "all-in-one" systems are characterized by the demineralization of tooth surfaces with simultaneous diffusion of adhesive monomers into demineralized tooth substance. One-Up Bond F has shown similar bond strengths to enamel and dentin (16-17 MPa) (Ogata & others, 1999; Yokota & others, 2001), although other studies have reported relatively low bond strengths to dentin of approximately 10-14 MPa (Koda, 2000; Sasao & others, 2000). One-Up Bond F created thinner hybrid layers in normal dentin than the other two adhesive systems used, probably due to the higher pH (1.8) all-in-one system that was not able to demineralize the dentin as well. According to previous work on caries-affected dentin (Nakajima & others, 1999), the thickness of the hybrid layer created was expected to be greater. However, in this study, One-Up Bond F could not form a well-circumscribed hybrid layer in caries-affected dentin. This same phenomenon has also been described by Yoshiyama & others (2000), who used Fluorobond, which is a self-etching primer with a separate adhesive. Although there is no correlation between the thickness of the hybrid layer and bond strength (Prati & others, 1998; Phrukkanon, Burrow & Tyas, 1999; Perdigão & others, 2000), the non-uniformity or absence of a hybrid layer could potentially lead to a poorer bond strength and increased likelihood of gap formation. This was seen as silver particles being precipitated at the interface between caries-affected dentin and the self-etching-priming-bonding resin. In addition, when a hybrid layer was created in caries-affected dentin, silver was deposited throughout almost its entire thickness. The acid-resistance and the permeability of caries-affected dentin are not still clear. Further studies should concentrate on the bonding mechanism of the all-in-one systems to caries-affected dentin.

The weak acidity of the all-in-one system minimized the demineralization of dentin and may have resulted in denatured dentin fragments remaining within caries-affected dentin after using the Carisolv system. The amorphous structures, lightly stained with silver in the adhesive resin, may be agglomerates of fluoroaluminosilicate glass fillers that are contained in the resin to release fluoride ions.

CONCLUSIONS

None of the current adhesive systems tested could eliminate nanoleakage even within the hybrid layer created in normal dentin. Nanoleakage patterns of caries-affected dentin seem to be different from those of normal dentin. The movement of fluids into these nanometer-sized spaces may affect the clinical performance of resin-based composite restorations especially for the cervical margins of deep cavities. This implies that hydrolytic degradation of the resin and/or collagen fibrils may occur, which may affect the durability of the bond. More research is required to further explain and determine how to prevent nanoleakage along the dentin walls of cavities as well as determine the effect of the bonding substrate. It would seem that the use of chemo-mechanical caries removal does not adversely affect the bond to caries-affected dentin.

Acknowledgements

This research was supported by the Fellowship for Japanese Scholars and Researchers to Study by the Ministry of Education, Science, Sports and Culture, Japan. The assistance of Jocelyn L Carpenter, School of Botany, The University of Melbourne, with the FE-SEM images is appreciated. The donation of materials by the manufacturers is acknowledged.

(Received 26 September 2001)

References

Banerjee A & Boyde A (1998) Autofluorescence and mineral content of carious dentine: Scanning optical and backscattered electron microscope studies *Caries Research* **32(3)** 219-226.

Banerjee A, Kidd EA & Watson TF (2000) *In vitro* evaluation of five alternative methods of carious dentine excavation *Caries Research* **34(2)** 144-150.

Beeley JA, Yip HK & Stevenson AG (2000) Chemochemical caries removal: A review of the techniques and latest developments *British Dental Journal* **188(8)** 427-430.

Cardoso PE, Placido E, Francci CE & Perdigão J (1999) Microleakage of Class V resin-based composite restorations using five simplified adhesive systems *American Journal of Dentistry* **12(6)** 291-294.

Cederlund A, Lindskog S & Blomlöf J (1999) Efficacy of Carisolv-assisted caries excavation *International Journal of Periodontics and Restorative Dentistry* **19(5)** 464-469.

Eick JD, Gwinnett AJ, Pashley DH & Robinson SJ (1997) Current concepts on adhesion to dentin *Critical Review in Oral Biology and Medicine* **8(3)** 306-335.

Fusayama T (1993) A simple pain-free adhesive restorative system by minimal reduction and total etching St Louis Ishiyaku Euro America Inc.

Hannig M (1999) Effect of Carisolv solution on sound, demineralized and denatured dentin—an ultrastructural investigation *Clinical Oral Investigations* **3(3)** 155-159.

Harnirattisai C, Inokoshi S, Shimada Y & Hosoda H (1992) Interfacial morphology of an adhesive composite resin and etched caries-affected dentin *Operative Dentistry* **17(6)** 222-228.

Koda K (2000) A study on light-cured resins—Chronological change of dentin bond strength of one-step systems with storage time *Japanese Journal of Conservative Dentistry* **43(3)** 684-694.

Kubo S, Yokota H, Sata Y & Hayashi Y (2000) Microleakage of cervical resin composite restorations *Modern trends in adhesive dentistry: Proceedings of the Adhesive Dentistry Forum '99 in Tsurumi, Yokohama* Osaka, Kuraray 1st edition 153-164.

Kubo S, Yokota H, Sata Y & Hayashi Y (2001) Microleakage of self-etching primers after thermal and flexural load cycling *American Journal of Dentistry* **14(2)** 163-169.

Li H, Burrow MF & Tyas MJ (2000a) Nanoleakage patterns of four dentin bonding systems *Dental Materials* **16(1)** 48-56.

Li H, Burrow MF & Tyas MJ (2000b) Nanoleakage of cervical restorations of four dentin bonding systems *Journal of Adhesive Dentistry* **2(1)** 57-65.

Li H, Burrow MF & Tyas MJ (2001) The effect of concentration and pH of silver nitrate solution on nanoleakage Submitted for publication.

Miyazaki M, Hinoura K, Saito H, Onose H & Moore BK (1995) Influence of light irradiation of dentine primers on dentine-resin bond *Journal of Dentistry* **23(6)** 371-374.

Nakabayashi N, Kojima K & Masuhara E (1982) The promotion of adhesion by the infiltration of monomers into tooth substrates *Journal of Biomedical Materials Research* **16(3)** 265-273.

Nakajima M, Sano H, Burrow MF, Tagami J, Yoshiyama M, Ebisu S, Ciucchi B, Russell CM & Pashley DH (1995) Tensile bond strength and SEM evaluation of caries-affected dentin using dentin adhesives *Journal of Dental Research* **74(10)** 1679-1688.

Nakajima M, Ogata M, Okuda M, Tagami J, Sano H & Pashley DH (1999) Bonding to caries-affected dentin using self-etching primers *American Journal of Dentistry* **12(6)** 309-314.

Nakajima M, Sano H, Urabe I, Tagami J & Pashley DH (2000) Bond strengths of single-bottle dentin adhesives to caries-affected dentin *Operative Dentistry* **25(1)** 2-10.

Ogata M, Nakajima M, Okuda M, Yamaguchi S, Harada N & Tagami J (1999) Tensile bond strengths of a newly developed one-step resin bonding system *Japanese Journal of Conservative Dentistry* **42(Autumn Issue)** 118.

Pashley EL, Talman R, Horner JA & Pashley DH (1991) Permeability of normal versus carious dentin *Endodontics and Dental Traumatology* **7(5)** 207-211.

Perdigão J, Swift EJ, Gomes G & Lopes GC (1999) Bond strengths of new simplified dentin-enamel adhesives *American Journal of Dentistry* **12(6)** 286-290.

Perdigão J, May KN Jr, Wilder AD Jr & Lopes M (2000) The effect of depth of dentin demineralization on bond strengths and morphology of the hybrid layer *Operative Dentistry* **25(3)** 186-194.

Phrukkanon S, Burrow MF & Tyas MJ (1998) The influence of cross-sectional shape and surface area on the microtensile bond strength test *Dental Materials* **14(3)** 212-220.

Phrukkanon S, Burrow MF & Tyas MJ (1999) The effect of dentine location and tubule orientation on the bond strengths between resin and dentine *Journal of Dentistry* **27(4)** 265-274.

Prati C, Chersoni S, Mongiorgi R & Montanari G & Pashley DH (1998) Resin-infiltrated dentin layer formation of new bonding systems *Operative Dentistry* **23(4)** 185-194.

Prati C, Chersoni S, Mongiorgi R & Pashley DH (1999) Thickness and morphology of resin-infiltrated dentin layer in young, old, and sclerotic dentin *Operative Dentistry* **24(2)** 66-72.

Prati C, Pashley DH, Chersoni S & Mongiorgi R (2000) Marginal hybrid layer in Class V restorations *Operative Dentistry* **25(3)** 228-233.

Sakooloamarka R, Burrow MF, Kubo S & Tyas MJ Morphological study of demineralized dentine after caries removal using two different methods *Australian Dental Journal* (accepted for publication).

Sano H (1987) Relationship between caries detector staining and structural characteristic of carious dentin *The Journal of the Stomatological Society, Japan* **54(1)** 241-270.

Sano H, Shono T, Sonoda H, Takatsu T, Ciucchi B, Carvalho R & Pashley DH (1994) Relationship between surface area for adhesion and tensile bond strength—Evaluation of a microtensile bond test *Dental Materials* **10(4)** 236-240.

Sano H, Takatsu T, Ciucchi B, Horner JA, Matthews WG & Pashley DH (1995) Nanoleakage: Leakage within the hybrid layer *Operative Dentistry* **20(1)** 18-25.

Sasao S, Miyamoto M, Oshita S, Kizuki I, Maseki T, Kimishima T, Nara Y, Dogon IL & Tanaka H (2000) Bonding of one-step resin adhesive systems to cervical tooth substance *Japanese Journal of Conservative Dentistry* **43(Spring Issue)** 154.

Van Meerbeek B, Mohrbacher H, Celis JP, Roos JR, Braem M, Lambrechts P & Vanherle G (1993) Chemical characterization of the resin-dentin interface by micro-Raman spectroscopy *Journal of Dental Research* **72(10)** 1423-1428.

Van Meerbeek B, Peumans M, Verschueren M, Gladys S, Braem M, Lambrechts P & Vanherle G (1994) Clinical status of ten dentin adhesive systems *Journal of Dental Research* **73(11)** 1690-1702.

Van Meerbeek B, Conn LJ Jr, Duke ES, Eick JD, Robinson SJ & Guerrero D (1996) Correlative transmission electron microscopy examination of nondemineralized and demineralized resin-dentin interfaces formed by two dentin adhesive systems *Journal of Dental Research* **75(3)** 879-888.

Vargas MA, Cobb DS & Armstrong SR (1997) Resin-dentin shear bond strength and interfacial ultrastructure with and without a hybrid layer *Operative Dentistry* **22(4)** 159-166.

Vargas MA, Cobb DS & Denehy GE (1997) Interfacial micromorphology and shear bond strength of single-bottle primer/adhesives *Dental Materials* **13(5)** 316-324.

Yip HK, Stevenson AG & Beeley JA (1994) The specificity of caries detector dyes in cavity preparation *British Dental Journal* **176(11)** 417-421.

Yokota H, Kubo S, Yokota H & Hayashi Y (2001) Effect of Caries Detector on dentin bond strengths *Japanese Journal of Conservative Dentistry* **44 (Spring Issue)** 115.

Yoshiyama M, Carvalho R, Sano H, Horner J, Brewer PD & Pashley DH (1995) Interfacial morphology and strength of bonds made to superficial *versus* deep dentin *American Journal of Dentistry* **8(6)** 297-302.

Yoshiyama M, Sano H, Ebisu S, Tagami J, Ciucchi B, Carvalho RM, Johnson MH & Pashley DH (1996) Regional strengths of bonding agents to cervical sclerotic root dentin *Journal of Dental Research* **75(6)** 1404-1413.

Yoshiyama M, Urayama A, Kimochi T, Matsuo T & Pashley DH (2000) Comparison of conventional vs self-etching adhesive bonds to caries-affected dentin *Operative Dentistry* **25(2)** 163-169.

©Operative Dentistry, 2002, **27**, 396-402

The Effect of Rebonding on Microleakage of Class V Aesthetic Restorations

MCG Erhardt • CS Magalhães • MC Serra

Clinical Relevance

Rebonding with a low-viscosity resin did not reduce the microleakage of the restorative systems evaluated.

SUMMARY

This in vitro **study evaluated the effect of rebonding on microleakage of a resin composite, a condensable resin and two polyacid-modified resin composite restorations. Standardized cylindrical Class V dentin cavities were prepared on the buccal root surfaces of 240 extracted bovine incisive teeth. The prepared teeth were randomly assigned to four groups of 60 teeth and restored with the following restorative systems: I—(ZS) Z100/Scotchbond Multi-Purpose Plus; II—(SS) Solitaire/Solid Bond; III—(FS) Freedom/Stae; IV—(FSB) F200/Single Bond. Thirty teeth of each group were rebonded with a low-viscosity resin (Fortify/BISCO), according to the manufacturer's instructions. The remaining teeth received no treatment. All teeth were thermocycled for 5,000 cycles and brushed by hand three times a day for 10 days using a toothbrush and a slurry of dentifrice and water. Specimens were stained in a 2% methylene blue solution and longitudinally sectioned with diamond disks. Microleakage was scored on a scale of 0 to 3. The Kruskal-Wallis test showed statistically significant differences among the groups (h=156.54; α<0.05). Pairwise comparison by means of the least significant difference showed that (SS) and (FS) with or without rebonding were not statistically different from each other. These groups showed the highest microleakage differences from (ZS) and (FSB) with or without rebonding. (ZS) with rebonding showed the lowest microleakage that was not statistically different from (ZS) without rebonding and (FSB) with rebonding.**

Maria Carolina Guilherme Erhardt, DDS, Fellow of "Fundação de Apoio à Pesquisa do Estado de São Paulo (FAPESP)," graduate student, Department of Restorative Dentistry, Piracicaba School of Dentistry, São Paulo, Brazil

Cláudia Silami Magalhães, DDS, MS, ScD, professor, Department of Restorative Dentistry, School of Dentistry, Federal University of Minas Gerais (UFMG), Brazil

*Mônica Campos Serra, DDS, MS, ScD, professor, Department of Restorative Dentistry, Ribeirão Preto School of Dentistry

*Reprint request: USP, Av do Café, s/ no—Monte Alegre, 14040-904— Ribeirão Preto—SP—Brazil; e-mail: mcserra@forp.usp.br

INTRODUCTION

Resin composites are routinely used as restorative materials in anterior and posterior teeth due to their excellent esthetic qualities (Burgess, 1995), satisfactory physical and mechanical properties (Ferracane, 1992; Htang, Ohsawa & Matsumoto, 1995) and high dissolution resistance (Htang & others, 1995).

However, polymerization shrinkage of the resin matrix is still considered highly relevant in unsuccessful resin composite direct restorations (Carvalho & others, 1996). The forces generated by polymerization shrinkage may induce stresses that could break the bonding at cavity walls, promoting marginal gaps, and subsequent microleakage (Davidson, de Gee & Feilzer, 1984). Clinical conditions associated with microleakage are breakdown and marginal discoloration, post-operative sensitivity and secondary caries and pulpal pathology, which have been considered reasons for replacing tooth-colored restorations (Qvist, Qvist & Mjör, 1990).

Composites are susceptible to water sorption, causing a volumetric expansion that could partially compensate for the polymerization shrinkage (Asmussen, 1985). If the hygroscopic expansion is great enough, tooth/restoration bonding could be preserved (Feilzer & others, 1995). However, during polymerization, contraction occurs rapidly, while water sorption is a slow process (Feilzer & others, 1995; Ferracane, 1992) and varies according to the level of the organic matrix and the type of filler particles (Feilzer & others, 1995; Htang & others, 1995).

Recently, packable composites have been developed as a possible alternative for dental amalgam. According to the manufacturers, these composites would present reduced polymerization shrinkage and superior marginal adaptation due to their monomer composition and filler incorporation (Leinfelder, 1997; Nash & Radz, 1998; Leinfelder, Bayne & Swift Jr, 1999).

Polyacid modified resin composites, described as water-free, single-component, light-cured composites, have been indicated for esthetic restorations (Class I, III and V) (Meyer, Cattani-Lorente & Dupuis, 1998). It has been suggested that the ionomeric portion of the material interferes in the kinetic polymerization of the resin component, promoting a slight reduction effect on the polymerization shrinkage (Crim, 1993).

The concept of rebonding to seal marginal gaps consists of applying an unfilled resin bonding agent over the margins of the finished restorations, to compensate for the adverse effect of the polymerization shrinkage on the tooth/restoration interface and to guarantee higher quality and durability of the marginal adaptation (García-Godoy & Malone, 1987; Judes & others, 1982; May & others, 1996; Reid, Saunders & Chen, 1991). Penetration of the unfilled resin by capillary action would seal the marginal gaps, reducing the microleakage (May & others, 1996). Rebonding has been demonstrated in clinical studies to significantly reduce wear and prolong marginal integrity (Dickinson & Leinfelder, 1993). The application of unfilled resins is also recommended to improve the quality of restorations made by glass ionomer/resin composite hybrid materials (Mount, 1994), repair the damaged surface after polishing at the tooth/restoration interface and control water balance (Ribeiro & others, 1999).

Therefore, this *in vitro* study evaluated the effect of the marginal rebonding technique on microleakage of Class V dentin cavities restored with resin composites or polyacid-modified resin composites.

METHODS AND MATERIALS

Two-hundred and forty recently extracted bovine incisive teeth were stored in 2% formalin solution pH 7, scaled, thoroughly cleaned, then polished with a slurry of pumice and water in a rubber prophylaxis cup at a low speed, in order to obtain a clean, smooth and hard surface. Standardized Class V dentin-type cavities were prepared using a cylindric diamond bur #015 (KG Sorensen, Barueri, SP, Brazil, 06454-920), in a high-speed handpiece (Dabi Atlante AS, Ribeirão Preto, SP, Brazil, 14095-000) with copious water-spray coolant, approximately 2.0 mm below the cement-enamel junction on the buccal root surface of each sample tooth. The cavity dimensions were approximately 1.5 mm in both width and depth. Cavosurface margins were finished to

Table 1: *Restorative Systems Used, Manufacturer, Batch #, Type of Material and Adhesive Composition*

Restorative System	**Manufacturer**	**Batch #**	**Type of Material/ Adhesive Composition**
Z100/SBMP Plus	3M Dental Products, St Paul, MN 55144,USA	8MT	Resin composite/ Primer: HEMA, polyalkenoic copolymer, water Adhesive: Methacrilic ester, acetone, butylated hydroxy toluene.
Solitaire/Solid Bond	Heraeus Kulzer GmbH, Phillip-Reis- Str 8/13, D-64273/Wehrhein, Germany	036	Packable Resin/ Solid Bond P: inorganic filler SiO_2 Solid Bond S: 2-hydroxyethyl methacrylat, acetone
Freedom/Stae	SDI/Southern Dental Industries L TD, Melbourne, 1800337003, Australia	70627	Polyacid-modified Resin composite/ Methacrylic ester, acetone, butylated hydroxy toluene
F2000/Single Bond	3M Dental Products, St Paul, MN 55144,USA	7 AX	Polyacid-modified Resin composite/ Bis-GMA, HEMA, dimethacrylates, polyalkenoic coplymer, ethanol
Fortify	BISCO Inc/1100 W Irwing Park Rd, Schaumburg, IL 60193, USA	119136	Light-cured, low viscosity, unfilled resin/ UDMA

a 90° angle using carbide cylindric burs (#56) at low-speed handpiece.

The prepared teeth were randomly assigned to four groups of 60 teeth and restored with one of the following materials according to the manufacturer's instructions. Table 1 describes the composition of the materials.

Group I—Resin composite–Z100/Scotchbond Multi-Purpose Plus

Scotchbond Multi-Purpose Etchant (37% phosphoric acid) was applied to the cavity for 15 seconds, rinsed with water for 15 seconds and air dried for two seconds, avoiding dentinal dehydration. Scotchbond Multi-Purpose Primer/3M was applied on the preparation and air dried for five seconds, leaving a shiny surface. Scotchbond Multi-Purpose Adhesive was applied to the primed cavity, brush thinned and light cured with a visible light source (Optilux 500–Demetron, Danbury, CT 06810, USA) for 20 seconds. The cavity was filled in bulk placement with the resin composite (Z100) and light cured for 40 seconds.

Group II—Condensable resin composite–Solitaire/ Solid Bond

The cavity was pretreated with Scotchbond Multi-Purpose Etchant (37% phosphoric acid) for 15 seconds and washed with air/water spray for 15 seconds. The cavity was air dried for two seconds, avoiding dessication. The primer (Solid Bond P) was brushed on the cavity for 30 seconds and air dried for two seconds to ensure solvent and water removal. The adhesive (Solid Bond S) was applied and light cured for 40 seconds, followed by inserting and packing of the resin (Solitaire) into the cavity with 40 seconds of light curing.

Group III—Polyacid-modified resin composite– Freedom/ STAE

Scotchbond Multi-Purpose Etchant (37% phosphoric acid) was applied into the cavity for 20 seconds and washed with an air/water spray for 15 seconds. The cavity was carefully dried, avoiding dentinal dehydration. The bonding agent (STAE) was brushed onto the cavity for 20 seconds and light cured for 20 seconds. The restorative material (Freedom) was injected into the preparation with a Centrix syringe (Centrix Inc, Shelton, CT 06484, USA), adapted to the margins of the restoration with a palette and light cured for 40 seconds.

Group IV—Polyacid-modified resin composite– F2000/ Single Bond

The cavity was pretreated with Scotchbond Multi-Purpose Etchant (37% phosphoric acid) for 15 seconds, subsequently washed with water for 15 seconds and dried with an absorbent paper disk. The bonding agent (Single Bond) was applied and light cured for 40 seconds. The resin (F2000) was inserted and adapted, followed by 40 seconds of light curing.

After six days of storing under moisture at 37°C (± 1°C), the restorations were finished and polished with medium, fine and extra-fine grit Al_2O_3 disks (Sof-Lex) under water spray coolant. Each restoration was visually evaluated to verify the superficial smoothness and the absence of restorative materials on the cavity margins.

Each group of 60 teeth, restored with the same material, was randomly assigned into two sub-groups. The experimental sub-group, containing 30 teeth of each group, was rebonded with a low-viscosity resin (Fortify-BISCO Inc) according to the manufacturer's instructions. The margins of the restorations were etched with 37% phosphoric acid for 10 seconds, subsequently rinsed for 20 seconds with water and air dried for five seconds. The low-viscosity resin was applied, the excess removed and it was finally light cured for 20 seconds. The remaining restorations were kept under moisture at 37°C (± 1°C), serving as unsealed controls. One operator did all the tooth preparation, restoration, finishing and rebonding.

All the teeth were brushed by hand three times a day at four-hour intervals for five days, using a soft toothbrush and 1 ml of a slurry of dentifrice (Sorriso/Kolynos do Brazil LTDA, 09883-000, Brazil) and water 3:1 (g/ml) (Ehrnford, 1983). The time spent brushing each tooth was 60 seconds at a force corresponding to appropriate clinical use. The teeth were also thermocycled in water for 2,500 cycles between five (±2°C) and 55 (±2°C), with dwell times of one minute in each bath and a transfer time of 15 seconds between baths (Rossomando & Wendt, 1995). The thermal and brushing cycles were alternated, beginning with the hand brush for five consecutive days, followed by the thermocycling for 2,500 cycles. This protocol was repeated, resulting in a total time of 30 minutes (60 seconds X 3 repetitions X 10 days) and 5000 thermocycles for brushing each tooth—representing an *in vivo* life span of approximately 1 1/2 years (de Wet & Ferreira, 1980).

The specimens were then prepared for dye penetration. The root apices were sealed with an epoxi resin and the surfaces covered by two coats of nail varnish within 1 mm of the restoration margins. Specimens were individually immersed in 5 ml of 2% methylene blue solution for four hours at room temperature, thoroughly rinsed with running water and carefully dried with absorvent papers.

Each tooth was longitudinally sectioned with a slow-speed diamond saw (KG Sorensen) in a buccal-lingual direction through the middle of the restorations. Both halves of each sectioned tooth were evaluated blind and independently by three evaluators who previously calibrated them with a stereomicroscope (Meiji Techno America, San Jose, CA 95131, USA) at x20 to determine the extent of dye penetration on the gingival and occlusal walls of the restorations.

The following criteria were used to score dye penetration: 0=no evidence of dye penetration; 1=evidence of dye penetration at the tooth/restoration interface extending less than one-half the distance to the axial wall; 2=dye penetration along the tooth/ restoration interface extending greater than one-half the distance to the axial wall but not to the axial wall; 3=dye penetration to the axial wall or beyond. The evidence of dye penetration in dentin was also evaluated through dicotomic criteria of penetration or non-penetration.

Table 2: *The Kruskal-Wallis Test for Median of Materials Tested, Sample Size, Average Ranks and Pairwise Comparision Among Groups by Means of Least Significant Difference*

Material/Treatment	Sample	Median Size	Average Ranks/ Cluster
Z100-SBMPPlus/rebonded (ZS)	30	0.5	51.5[a]
Z100-SBMPPlus/not rebonded (ZS)	30	0.75	62.7[ab]
F200-Single Bond/rebonded (FSB)	30	1	74.2[ab]
F200-Single Bond/not rebonded (FSB)	30	1	89.4[b]
Solitaire-Solid Bond/not rebonded (SS)	30	3	165.1[c]
Solitaire-Solid bond/rebonded (SS)	30	3	170.4[c]
Freedom-Stae/rebonded (FS)	29	3	172.2[c]
Freedom-Stae/not rebonded (FS)	30	3	176.4[c]

Values followed by the same letter did not differ from each other (α<0.05) lsd (29.30) = 35.28 ; lsd (30.30) = 34.97

Data were analyzed by the Kruskal-Wallis non-parametric test by Statigraphs software (Manugistics Inc, Rockville, MD 28852, USA). The median from 12 observations (2 halves x 2 walls x 3 examiners) was taken in each experimental unit. The data from all groups were first combined and ranked from smallest to largest. The average rank was then computed for the data of each group. To determine which medians were significantly different from each other, pairwise comparison was employed to check the hypothesis of equality among the groups of materials studied by means of the least significant difference (Campos, 1983). The percentage of specimens that showed dye penetration through dentin was calculated.

RESULTS

The sample size, microleakage median scores, average ranks per group of studied materials and pairwise comparisons are presented in Table 2. The Kruskal Wallis test showed statistically significant differences among the groups at the 5% probability level (h=156.54; α<0.05).

Results of the Kruskal Wallis test showed that treatments differ among themselves (α<0.05). To perform a Kruskal Wallis test, first, observations were ranked in ascending order and rank #1 was considered to have the lowest microleakage. Subsequently, the sum of ranks per group was calculated and average ranks were considered to perform pairwise comparisons between the groups by means of the least significant difference (lsd).

Comparisons of the average ranks showed that Freedom (FS) with rebonding, Freedom (FS) without rebonding, Solitaire (SS) with rebonding and Solitaire (SS) without rebonding did not statistically differ from each other. These groups showed the highest microleakage scores that were statistically different from F2000 (FSB) with and without rebonding. Z100 (ZS) with rebonding showed the lowest microleakage scores that were not statistically different from Z100 (ZS) without rebonding and F2000 (FSB) with rebonding. Table 3 presents the percentage of specimens that showed dye penetration through.

Table 3: *Percentage of Specimens That Showed Dye Penetration Through Dentin*

Material/Treatment	Percentual (%)
Freedom-Stae/rebonded	89.65
Freedom-Stae/not rebonded	86.66
Solitaire-Solid Bond/rebonded	86.66
Solitaire-Solid Bond/not rebonded	83.33
F2000-Single Bond/rebonded	16.37
Z100-SBMP Plus/not rebonded	16.37
F2000-Single Bond/not rebonded	13.34
Z100-SBMPPlus/rebonded	13.34

DISCUSSION

Despite the constant development of dentin bonding adhesives, glass ionomer hybrid materials and resin composites, the marginal sealing of cervical restorations still deserves considerable study (May & others, 1996). The degree of shrinkage and the physical and rheological properties of the restorative materials may have an influence on the results of comparative studies of dye penetration (Déjou, Sindres & Camps, 1996). Polyacid-modified resins have shown comparable results to hybrid resin composites in microleakage studies (de-Magalhães, Serra & Rodrigues, 1999; Rodrigues & others, 1999). Their performance may change according to the composition of the different products on the market.

The recently developed condensable resin Solitaire presented significantly higher microleakage scores. These results do not agree with the ones found by Nash

& Radz (1998), which showed better marginal adaptation with the use of Solitaire when compared to a hybrid resin composite. An evaluation of the polymerization contraction of different composites showed that Solitaire had the highest values (Norling & others, 1999). The higher consistency of the condensable resin could explain the highest levels of microleakage found in this material when compared to a microfilled resin composite (Francci & others, 1999). The degree of shrinkage, the stiffness of the material and the bond resistance to tooth structure can predict the performance of the material when microleakage is analyzed (Goracci, Mori & Martinis, 1996).

In this study, the chemical composition of the adhesive system seemed to be more relevant than the restorative materials used. Although microleakage was not avoided, the adhesives with water in their composition as a solvent or a co-solvent associated with a hybrid resin composite (Z100/SBMP Plus) or with a polyacid-modified resin composite (F2000/Single Bond) showed significantly less microleakage than adhesives with acetone in their composition as a solvent associated with a condensable resin (Solitaire/Solid Bond) or with a polyacid-modified resin composite (Freedom/STAE).

Having an adequate proportion of water is important for the efficacy of the adhesion of acetone-based systems (Perdigão, Ramos & Lambrechts, 1997). It is recommended that dentin should be kept wet after acid etching to permit the collagen net fibrils that are exposed to remain flexible and permeable for the primer application (Van Meerbeek & others, 1998). Although the manufacturer's recommendations were followed, the acetone-based adhesives seemed to be more appropriate to the experimental conditions regarding the maintenance of humidity. The adhesive systems with water in their composition promote the re-wetting of the collagen fibrils where no humidity is present (Van Meerbeek & others, 1998). Besides water, Single Bond and SBMP Plus present polyalcenoics acids in their composition. These acids show some resistance to humidity, while the complex formed between them and calcium ions show an intrinsic ability to promote absorption of the polymerization stress contraction (Perdigão & others, 1997). Such adhesives are associated with the formation of a thick resin layer with a low elasticity module on the hybrid layer, which absorbs the "stress" induced by the polymerization contraction of the restorative material (Perdigão & others, 1997). This study showed that despite using dentinal adhesives, none of the restorative systems available presented a microleakage-free restoration.

Using an unfilled resin to rebond dentin margins did not significantly reduce the microleakage for any of the systems used. These findings agree with the results of May & others (1996), but they disagree with the results of Judes & others (1982); Torstenson, Brännström & Mattsson (1985); García-Godoy & Malone (1987); Reid & others (1991); Tjan & Tan (1991) and Munro & others (1996). However, the direct comparison of these results is compromised due to material diversity and the methods and criteria of evaluation used in the different studies of microleakage. The cavity margins localization in enamel, dentin or sometimes both, is one of the most important factors that influence these results.

In the oral environment, Class V restorations are submitted to abrasive wear by brushing and variations in temperature. In this study, a brushing cycle combined with a thermal cycle has been performed in an attempt to simulate these conditions. The low viscosity resin probably had only covered the gaps without penetrating them deeply due to the incomplete wetting of the surface caused by the presence of air bubbles, humidity or debris (Tjan & Tan, 1991). Brushing associated with the thermal cycle may have produced loss of the fluid resin layer (Reid & others, 1991), which would explain the absence of significant differences between the groups with and without rebonding. The integrity of the tooth-restoration interface could be dependent on the durability of the adhesive system used and the unfilled resin that has penetrated into the margins of the restorations.

The rebonding technique has already been used in the past with glazes, but its benefits were limited due to inadequate adhesion to composites and accelerated wearness, which decreased its longevity (de Wet & Ferreira, 1980). Improvements in this technique could be found in the development of a sealant of even lower viscosity, to increase its penetration ability (Kemp-Scholte & Davidson, 1988). The rebonding procedure has been indicated as a means to improve the marginal sealing by gap impregnation with an unfilled resin or adhesive (García-Godoy & Malone, 1987; Judes & others, 1982; Munro & others, 1996; Reid & others, 1991; Tjan & Tan, 1991; Torstenson & others, 1985). Although the need for etching prior to rebonding is somewhat controversial, in this study, etching was used before rebonding to enhance resin adhesion and remove any acid-soluble substances that may have contaminated the restoration and adjacent tooth structure during restoration, finishing and polishing (Dutton & others, 1993). These results agree with those of Draheim, García-Godoy & Titus, 1989, which reported no statistically significant difference among conventionally placed composites, rebonded composites or acid-etch before rebonding composites.

Dentinal tubule dye penetration was recorded to evaluate the severity of microleakage, thus, indicating the efficacy of the adhesive along the cavity walls. The dye penetration percentage in dentin reproduced the tendency registered by the ordinal scale. The materials that showed high microleakage scores also had more penetration in dentin. The lower penetration percentage in dentin showed that although an adhesive interface failure had occurred, dentin remained sealed and protected by the integrity of the hybrid layer (Applequist & Meiers, 1996).

Clinical observations showed that none of the restorative systems available seemed to totally guarantee sealed restorations free of discoloration over the long-term (Van Meerbeek & others, 1998). The progressive loss of marginal integrity and consequent microleakage is mainly caused by "stress" resulting from the polymerization contraction and thermo-dimensional alterations of the restorative material. The progress of adhesive dentistry still depends on developing restorative materials of low contraction, with thermal expansion coefficients closer to the tooth structure (Van Meerbeek & others, 1998).

This study showed that regardless of the choice of the material and the rebonding technique, all restorative systems tested resulted in microleakage. Variations of scores depended on the intrinsic material properties of the restorative materials and the adhesive systems used. The extremely soft rebonding layer may quickly wear when exposed to routine intraoral abrasive and thermal conditions, thus losing its effectiveness. Long-term clinical investigations must still be conducted to assess the real longevity of this marginal sealing technique.

CONCLUSIONS

1. Rebonding with a low-viscosity resin did not reduce marginal leakage of the restorative systems evaluated.
2. The restorative systems Freedom/Stae (polyacid-modified resin composite) and Solitaire/Solid Bond (condensable resin) showed significantly higher microleakage than Z100/SBMP Plus (resin composite) and F2000/Single Bond (polyacid-modified resin composite).

Acknowledgements

The authors thank Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP/grant #98/13279-1) for support of this research.

(Received 21 September 2001)

References

Applequist EA & Meiers JC (1996) Effect of bulk insertion, prepolymerized resin composite balls, and beta-quartz inserts on microleakage of Class V resin composite restorations *Quintessence International* **27(4)** 253-258.

Asmussen E (1985) Clinical relevance of physical, chemical, and bonding properties of composite resins *Operative Dentistry* **10(2)** 61-73.

Burgess JO (1995) Dental materials for the restoration of root surface caries *American Journal of Dentistry* **8** 342-351.

Campos H (1983) *Estatística Experimental não-Paramétrica* 3ª edição, Piracicaba: ESALQ/USP p 348.

Carvalho RM, Pereira JC, Yoshiyama M & Pashley DH (1996) A review of polymerization contraction: The influence of stress development versus stress relief *Operative Dentistry* **21(1)** 17-24.

Crim GA (1993) Marginal leakage of visible light-cured glass-ionomer restorative materials *Journal of Prosthetic Dentistry* **69(6)** 561-563.

Davidson CL, de Gee AJ & Feilzer A (1984) The competition between the composite-dentin bond strength and the polymerization contraction stress *Journal of Dental Research* **63(12)** 1396-1399.

Déjou J, Sindres V & Camps J (1996) Influence of criteria on the results of *in vitro* evaluation of microleakage *Dental Materials* **12(6)** 342-349.

de-Magalhães CS, Serra MC & Rodrigues AL Jr (1999) Volumetric microleakage assessment of glass-ionomer-resin composite hybrid materials *Quintessence International* **30** 117-121.

de Wet FA & Ferreira MR (1980) The durability of dental glazes *Journal of Prosthetic Dentistry* **44(3)** 300-306.

Dickinson GL & Leinfelder KF (1993) Assessing the long-term effect of a surface penetrating sealant *Journal of the American Dental Association* **124(7)** 68-72.

Draheim RN, García-Godoy F & Titus HN (1989) Microleakage of microfilled composite in enamel using two rebonding methods *Trans Academy of Dental Materials* **2** 27-28.

Dutton FB, Summit JB, Chan DCN & García-Godoy F (1993) Effect of a resin lining and rebonding on the marginal leakage of amalgam restorations *Journal of Dentistry* **21(1)** 52-56.

Ehrnford L (1983) Surface microstructure of composites resins after toothbrush-dentifrice abrasion *Acta Odontologica Scandinavica* **41(4)** 241-245.

Feilzer AJ, Kakaboura AI, de Gee AJ & Davidson CL (1995) The influence of water sorption on the development of setting shrinkage stress in traditional and resin-modified glass-ionomer cements *Dental Materials* **11(3)** 186-190.

Ferracane JL (1992) Using posterior composites appropriately *Journal of the American Dental Association* **123(7)** 53-58.

Francci C, Perdigão J, Cardoso PEC, Meira JBC & Nunes MF (1999) The effect of composite resin, adhesive system, and low-viscosity liner on microleakage *Journal of Dental Research* **78(Special Issue)** Abstract #2263 pg 388.

García-Godoy F & Malone WFP (1987) Microleakage of posterior composite restorations after rebonding *Compendium of Continuing Education in Dentistry* **8(8)** 606-609.

Goracci G, Mori G & Martinis LC (1996) Curing light intensity and marginal leakage of resin composite restorations *Quintessence International* **27** 355-362.

Htang A, Ohsawa M & Matsumoto H (1995) Fatigue resistance of composite restorations: Effect of filler content *Dental*

Materials **11(1)** 7-13.

Judes H, Eli I, Lieberman R, Serebro L & Ben Amar A (1982) Rebonding as a method of controlling marginal microleakage in composite resin restorations *The New York Journal of Dentistry* **52(5)** 137-143.

Kemp-Scholte CM & Davidson CL (1988) Marginal sealing of curing contraction gaps in Class V composite resin restorations *Journal of Dental Research* **67(5)** 841-845.

Leinfelder KF (1997) New developments in resin restorative systems *Journal of the American Dental Association* **128(5)** 573-581.

Leinfelder KF, Bayne SC & Swift EJ Jr (1999) Packable composites: Overview and technical considerations *Journal of Esthetic Dentistry* **11(5)** 234-249.

May KN Jr, Swift EJ Jr, Wilder AD Jr & Futrell SC (1996) Effect of a surface sealant on microleakage of Class V restorations *American Journal of Dentistry* **9(3)** 133-136.

Meyer JM, Cattani-Lorente & Dupuis (1998) Compomers: Between glass-ionomer cements and composites *Biomaterials* **19(1)** 529-539.

Mount GH (1994) Glass-ionomer cements: Past, present and future *Operative Dentistry* **19(3)** 82-90.

Munro GA, Hilton TJ & Hermesch (1996) *In vitro* microleakage of etched and rebonded Class V composite resin restorations *Operative Dentistry* **21(5)** 203-208.

Nash RW & Radz GM (1998) A report on a new condensable composite resin *Compendium* **19(3)** 230-237.

Norling BK, Wilson BL, Wellinghoff HL & Cardenas HR (1999) Cure shrinkage of composite resins and an experimental LC monomer *Journal of Dental Research* **78(Special Issue)** Abstract #1020 pg 233.

Perdigão J, Ramos JC & Lambrechts P (1997) *In vitro* interfacial relationship between human dentin and one-bottle dental adhesives *Dental Materials* **13(4)** 218-227.

Qvist V, Qvist J & Mjör IA (1990) Placement and longevity of tooth-colored restorations in Denmark *Acta Odontologica Scandinavica* **48(5)** 305-311.

Reid JS, Saunders WP & Chen YY (1991) The effect of bonding agent and fissure sealant on microleakage of composite resins restorations *Quintessence International* **22(4)** 295-298.

Ribeiro APG, Serra MC, Pauillo LAMS & Rodrigues AL Jr (1999) Effectiveness of surface protection for resin-modified glass-ionomer materials *Quintessence International* **30(6)** 427-431.

Rodrigues JA, Magalhães CS, Serra MC & Rodrigues AL Jr (1999) *In vitro* microleakage of glass-ionomer composite resin hybrid materials *Operative Dentistry* **24(2)** 89-95.

Rossomando KJ & Wendt SL Jr (1995) Thermocycling and dwell times in microleakage evaluation for bonded restorations *Dental Materials* **11(1)** 47-51.

Tjan AHL & Tan DE (1991) Microleakage at gingival margins of Class V composite resin restorations rebonded with various low-viscosity resin systems *Quintessence International* **22(7)** 565-573.

Torstenson B, Brännström M & Mattsson B (1985) A new method for sealing composite resin contraction gaps in lined cavities *Journal of Dental Research* **64(3)** 450-453.

Van Meerbeek B, Yoshida Y, Lambrechts P, Vanherle G, Duke ES, Eick JD & Robinson SJ (1998) A TEM study of two water-based adhesive systems bonded to dry and wet dentin *Journal of*

©*Operative Dentistry*, 2002, **27**, 403-409

Bond Strength of Two Adhesive Systems to Primary and Permanent Enamel

Y Shimada • P Senawongse • C Harnirattisai
MF Burrow • Y Nakaoki • J Tagami

Clinical Relevance

Bonding to primary enamel with a self-etching primer system or a single-bottle adhesive system is potentially as good as bonding to permanent enamel.

SUMMARY

The bonding performance of current adhesive systems to primary enamel has not been thoroughly researched. This study compared the micro-shear bond strength of two adhesive systems to primary and permanent tooth enamel. Two commercially available resin adhesives, a self-etching primer system (Clearfil SE Bond) and a single-bottle adhesive system (Single Bond) used with a total-etch wet bonding technique were tested. A micro-shear bond test was used to examine the adhesive systems on mid-coronal buccal enamel of extracted primary or permanent teeth. In addition, etched enamel surfaces and etched-bonded enamel interfaces were examined using scanning electron microscopy (SEM). No statistically significant differences of shear bond strength values were found between the primary and permanent enamel or the adhesive systems used (p>0.01). The SEM observations showed that both adhesive systems etched the primary enamel deeper than the permanent enamel, suggesting that the action of acid etch seemed to be more intense on primary enamel than on permanent enamel. Bonding of the adhesive systems to primary enamel was almost identical to permanent enamel.

Yasushi Shimada, DDS, PhD, instructor, Cariology and Operative Dentistry, Department of Restorative Sciences, Graduate School, Tokyo Medical and Dental University

Pisol Senawongse, DDS, graduate student

Choltacha Harnirattisai, DDS, PhD, associate professor, Department of Operative Dentistry, Faculty of Dentistry, Bangkok, Thailand

Michael F Burrow, MDS, PhD, associate professor, School of Dental Science, University of Melbourne

Yasuko Nakaoki, DDS, PhD, instructor

Junji Tagami, DDS, PhD, professor and chair

*Reprint request: 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8549, Japan; e-mail: shimada.ope@tmd.ac.jp

INTRODUCTION

The provision of adhesive resin composite restorations to treat discolored, malformed, carious or traumatized primary teeth is becoming more common. This has often been regarded as challenging, since the widely held belief is that bonding to primary tooth enamel is not as reliable as bonding to permanent tooth enamel (Salama & Tao, 1991; Bordin-Aykroyd, Sefton & Davies, 1992; El Kalla & García-Godoy, 1998; Senawongse & others, 2002; Olmez & others, 1998; Nör & others, 1996). An effective bond to primary enamel and dentin would

Table 1: *Materials Used*

Materials	Batch	Composition
ClearFil SE Bond	#011161	
Primer		10-Methacryloyloxydecyl dihydrogen phosphate (MDP) 2-Hydroxyethyl methacrylate (HEMA) Hydrophilic dimethacrylate dl-Camphorquinone, Aromatic tert-amine, Water
Bond Liquid		MDP, Bis-phenol A diglycidylmethacrylate (Bis-GMA), HEMA, Hydrophobic dimethacrylate Photo initiator, Aromatic tert-amine, Silanated colloidal silica
Single Bond	#19981008	
Etchant		35% Phosphoric acid
Adhesive		HEMA, BisGMA, Dimetacrylates, Metacrylate, Functional copolymer (polyacrylic and polyitaconic
acids),		Photoinitiator, ethanol, water
Clear AP-X	#-1251	Light-curing hybrid resin composite

Table 2: *Application Techniques*

Procedure	Time
Single Bond System	
(1) Apply etchant	15 seconds
(2) Rinse	15 seconds
(2) Blot dry with absorbent paper	-
(3) Apply two coats of adhesive	-
(4) Apply light cure	20 seconds
Clearfil SE Bond System	
(1) Apply primer	10 seconds
(2) Dry	-
(3) Apply adhesive	-
(4) Apply light cure	20 seconds

reduce marginal microleakage, bacterial penetration that leads to recurrent decay, postoperative sensitivity and the possibility of pulpal inflammation, as well as preserve tooth structure, thus allowing more conservative cavity preparation (Salama & Tao, 1991; Bordin-Aykroyd & others, 1992; El Kalla & García-Godoy, 1998; Senawongse & others, 2002; Brännström & Nyborg, 1973; Davidson, de Gee & Feilzer, 1984; Sano & others, 1995). The newest dentin bonding agents resist the contraction forces of cured resin composite in permanent tooth structure (Nakabayashi, Kojima & Masuhara, 1982; Kanca, 1992; Watanabe, Nakabayashi & Pashley, 1994; Sano & others, 1994; Kanemura, Sano & Tagami, 1999; Shinchi, Soma & Nakabayashi, 2000). However, failures of restorations in primary teeth are still a common problem (Salama & Tao, 1991; Bordin-Aykroyd & others, 1992; El Kalla & García-Godoy, 1998; Senawongse & others, 2002; Olmez & others, 1998; Nör & others, 1996). One of the problems related to using complicated adhesive systems to treat the primary dentition is the time required for the various steps and the associated technique sensitivity. To overcome this, systems such as self-etching and priming adhesive materials usually take less time to complete the bonding process. In addition, these systems tend to be technique sensitive. Both of these factors become quite important when a patient may be uncooperative during treatment.

In the case of the primary dentition, little is known about the bonding performance to enamel using recent adhesives, such as self-etching priming systems (Hirayama, 1990). This is probably due to the difficulty in standardizing the plane of enamel and obtaining a sufficient surface area for bonding. Recently, a micro-shear bond test was developed that can be used to measure bond strengths to extremely small areas (Shimada & others, 1999, 2002).

This study investigated the bonding performance to primary tooth enamel using a self-etching primer system or an acid-etch, single-bottle adhesive system. The micro-shear bond test was used to assess the bond strengths. The etched enamel surface and the adhesive interface between the enamel and resin were studied using scanning electron microscopy (SEM).

METHODS AND MATERIALS

Sixty-four extracted human caries-free teeth—32 primary molars and 32 permanent molars—were stored frozen. Sixty enamel slices, approximately 1.0 mm thick, were obtained from buccal surfaces by cutting with a slow rotating diamond blade (Struers Minitom, Struers, Copenhagen, Denmark) under water spray. The enamel surfaces were resurfaced with wet 280-grit SiC paper until a depth half way between the dentin enamel junction and outer surface was obtained.

Table 1 lists the compositions and manufacturers of the materials used in this study. The systems investigated were: Clearfil SE Bond (Kuraray Co, Osaka, Japan), which includes a self-etching primer and a bonding agent and Single Bond (3M, St Paul, MN 55144 USA), which uses 35% phosphoric acid etchant and a one-bottle adhesive intended for use with the wet bonding technique. Application techniques for each of the adhesive systems are summarized in Table 2. All the materials were handled according to the manufacturer's instructions.

Micro-Shear Bond Test

Twenty primary enamel slices and 20 permanent enamel slices were randomly selected for bonding with

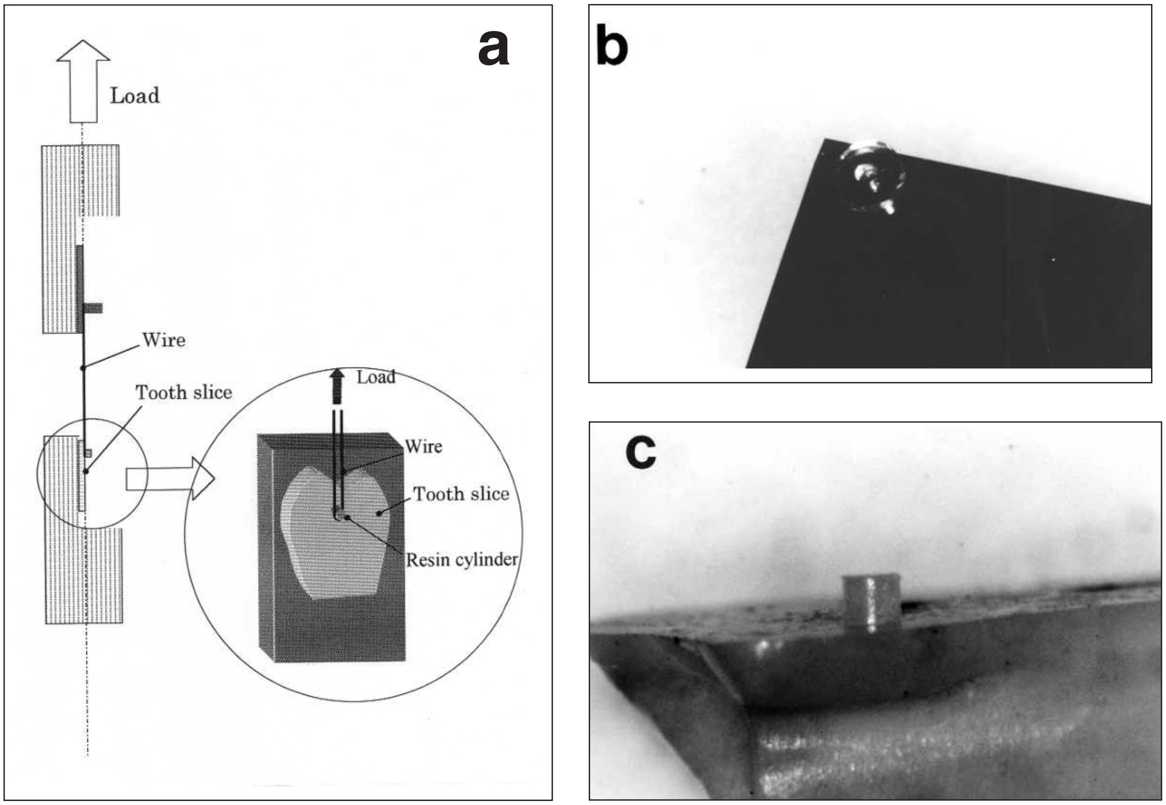


Figure 1.
(a) Schematic of micro-shear bond test apparatus.
(b) Cut tygon tubing.
(c) Resin cylinder bonded on enamel surface.

one of the adhesives. (Table 2). Prior to irradiation of the bonding resin, a cylinder from micro bore tygon tubing (R-3603, Norton Performance Plastic Co, Cleveland, OH 44309, USA) with an internal diameter of 0.8 mm and a height of 0.5 mm was cut and mounted on the enamel to restrict the bonding area. A hybrid restorative resin composite, shade A3 (Clearfil AP-X, Kuraray Co, Osaka, Japan) was placed into the cylinder and a clear celluloid sheet was placed over the resin and gently pressed flat and irradiated for 40 seconds. Because the tygon cylinder was bonded tightly to the enamel surface by the bonding resin simultaneously with the photocuring of the bonding resin, no flash of resin composite extended onto the enamel beyond the base of the cylinder. In this manner, very small cylinders of resin, approximately 0.8 mm in diameter and 0.5 mm in height, were bonded to the surface. The specimens were stored at room temperature (23°C) for one hour prior to removing the tygon tubing. The specimens were then stored in water at 37°C for 24 hours.

Before the microshear test, all samples were checked under an optical microscope (magnification = 30x) for defects. Samples that showed interfacial gap formation or bubble inclusion were excluded from the study and replaced with another sample.

Figure 1 shows the micro-shear bond test apparatus. The tooth slice with the resin cylinders was attached to the testing device (Bencor-Multi-T, Danville Engineering Co, San Ramon, CA 94583, USA) with a cyanoacrylate adhesive (Zapit, Dental Ventures of America, Corona, CA 92882, USA), which in turn was placed in a Universal testing machine (Eztest-500N, Shimazu Co, Kyoto, Japan) for shear bond testing. A thin wire (diameter 0.20 mm) was looped around the resin cylinder, making contact with half of the cylinder base and it was held flush against the resin/enamel interface. A shear force was applied to each specimen at a crosshead speed of 1.0 mm/minute until failure occurred. The resin-enamel interface for the test, the wire loop and the center of the load cell were aligned as straight as possible to ensure that the desired orientation in shear stress was maintained.

Ten specimens were tested for each group. The data were statistically analyzed using two-way ANOVA and Fisher's PLSD test at the 99% level of confidence. All the debonded enamel surfaces after the shear test were examined under an optical microscope at 30x magnification and SEM (JXA840, JEOL Ltd, Tokyo, Japan), so that the mode of failure could be identified. The failure modes were categorized into one of three types: A: 100% adhesive failure between enamel or enamel-resin hybrid-like layer and adhesive resin; B: 100% cohesive failure in enamel and C: Mixed failure with adhesive failure (A) and cohesive failure in enamel (B).

SEM Observation

Twelve additional enamel slices from primary and permanent teeth were used for the SEM study.

Specimens were prepared to observe the etch pattern of the phosphoric acid gel and the self-etching primer.

Twelve enamel specimens, composed of six slices of primary and permanent teeth, were etched or primed in the same manner as the shear bond test specimens. The slices treated with the self-etching primer were given a 60-second acetone rinse to remove any loose enamel crystals or other residue remaining from the primer. Surfaces were sputter-coated with gold and observed under a SEM.

The interfacial structure between the enamel and the resin on six primary tooth samples and six permanent tooth samples was observed. Six bonded enamel-resin interfaces (three interfaces for each adhesive system) were prepared in the same manner as that employed for the shear bond test and were sectioned in half, ground and polished using wet silicon carbide papers and diamond pastes of decreasing particle size down to 0.25 mm. Each group comprised three teeth for which two resin-enamel interfaces were made. Hence, six specimens (n=6) were examined for each group. The two halves of each cut specimen were placed in a vacuum overnight, gold sputter-coated and examined under SEM.

RESULTS

Table 3: *Micro-shear Bond Strength (MPa ± SD)*

	Bonding System	
	Single Bond	Clearfil SE Bond
Primary	37.0 ± 7.95	42.7 ± 4.32
Permanent	42.7 ± 8.35	42.9 ± 7.54

SD is the standard deviation of the measurement.

Table 4: *Frequency of Mode of Failure After Shear Bond Testing*

	Single Bond			SE Bond		
	A	B	C	A	B	C
Primary	9	0	1	9	0	1
Permanent	8	0	2	9	0	1

A: 100% adhesive failure between enamel or hybrid enamel layer and adhesive resin; B: 100% cohesive failure in enamel; C: Mixed failure with adhesive failure (A) and cohesive failure in enamel (B).

Micro-Shear Bond Test

Table 3 shows the mean shear bond strengths and standard deviations. Two-way ANOVA indicated that there was no variation between the adhesive systems and the type of dentition (p=0.239). Fisher's PLSD test also indicated that no significant difference was observed between the adhesive systems (SE Bond vs Single Bond, p=0.208) or the kinds of dentition (primary vs permanent, p=0.209).

Table 4 shows the data of mode of failure. No differences in failure modes were found between the bonding systems used or the kinds of dentition. Figure 2 shows the SEM photomicrographs of the debonded specimens. Cohesive failures within resin composite were not observed. Failure mostly occurred between the enamel or the enamel-resin hybrid-like layer and the overlying adhesive resin, with type A failures occurring most frequently.

SEM Observations

SEM photomicrographs of enamel surfaces etched with phosphoric acid gel or self-etching primer are shown in Figure 3. The application of 35% phosphoric acid gel for 30 seconds selectively etched the prismatic structure of both the primary and the permanent enamel surfaces (Figures 3a, b). In the case of the self-etching primer, the enamel surfaces after acetone rinsing showed a less distinct pattern (Figures 3c, d). Nonetheless, the permanent enamel treated with the self-etching primer showed less prominent enamel prisms and micro-irregularities of the hydroxyapatite crystals were apparent (Figure 3c). Figure 3d shows the etched pattern of primary enamel. Unlike permanent enamel, the enamel prisms were easily identified. When the effects of the acid gel or the acidic primer on both types of dentition were compared, the etch pattern of primary enamel seemed more distinct and deeper than the permanent enamel.

Figure 4 shows the micromorphology of adhesive interfaces between the enamel and the resin. When phosphoric acid gel was applied, micro-mechanical interlocking with extensive enamel tag formation was obvious in both types of dentition (Figures 4a, b). The depth of etched enamel was approximately 10 µm in the permanent enamel and 13 µm in the primary enamel.

In the case of the self-etching primer, even though the formation of etched enamel tags was not as evident compared with phosphoric acid etching, micro-mechanical interlocking and resin-tag formation with both primary and permanent enamel were observed

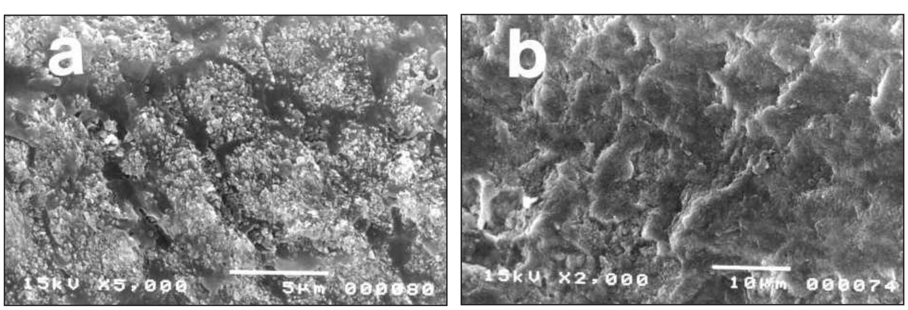
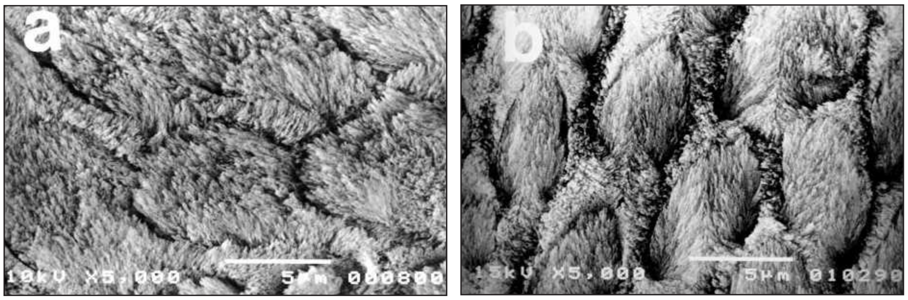
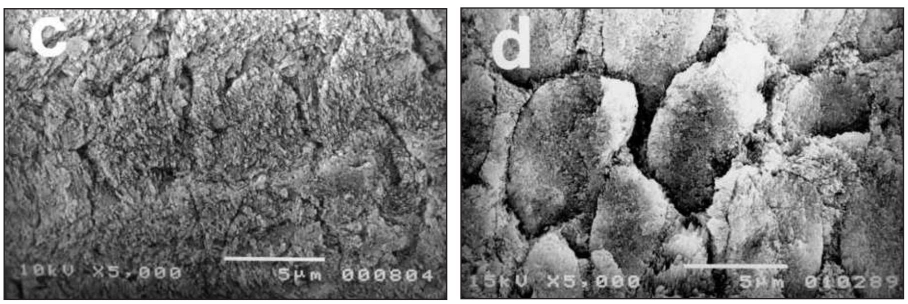


Figure 2. *SEM images of debonded sites after the micro-shear bond test.*
(a) Single Bond. Primary tooth enamel. Type A failure occurred. Remnants of bonding resin remained on the enamel surface.
(b) Clearfil SE Bond. Primary tooth enamel. Type A failure occurred.

Figure 3. *SEM images of conditioned tooth surfaces.*



(a) Permanent tooth etched by 35 wt% phosphoric acid gel for 15 seconds. Enamel prisms are easily identified. The enamel surface is roughened, and micro-irregularity based on hydroxyapatite crystals is apparent.
(b) Primary tooth enamel etched by 35% phosphoric acid gel for 15 seconds. Enamel prisms are also easily identified. Compared with (a), the enamel surface is more deeply roughened.



(c) Permanent tooth enamel conditioned by Clearfil SE Bond primer for 20 seconds. By acetone rinsing, most of the smear layer was removed. Enamel surface was slightly roughened by the acidic primer.
(d) Primary tooth enamel conditioned by Clearfil SE Bond primer for 20 seconds. Compared with (c), the enamel surface is deeply etched and enamel prisms are identified.

(Figures 4c, d). The depth of the etched enamel was approximately 1 µm, and there was no clear difference between the two types of dentition.

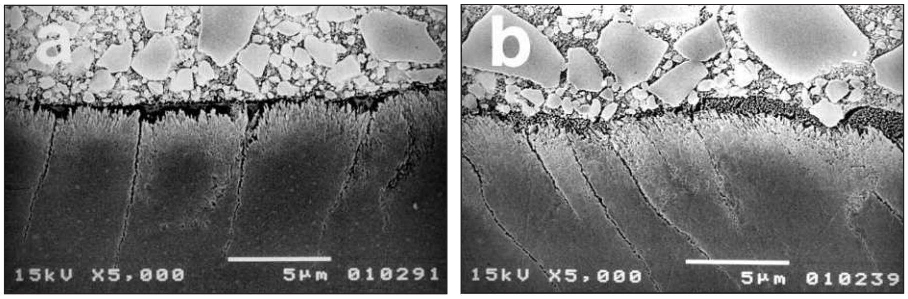
DISCUSSION

A number of studies have been performed to investigate the bonding ability of adhesive systems to tooth structure, including tensile and shear bond tests (Salama & Tao, 1991; Bordin-Aykroyd & others, 1992; El Kalla & García-Godoy, 1998; Senawongse & others, 2002; Sano & others, 1994; Kanemura & others, 1999; Shimada & others, 1999); however, there seems to be minimal study of how primary enamel can bond with resin-based adhesive systems. Since the development of a micro-bond test by Sano & others (1994), many micro-bond tests have been performed using a tensile method (Sano & others, 1994; Kanemura & others, 1999). The information derived from micro-bond testing is an effective method in terms of testing small areas of tooth structure (Sano & others, 1994; Kanemura & others, 1999). For testing "micro-tensile" bonds, however, trimming of the specimen is an indispensable step for making small samples (Sano & others, 1994; Kanemura & others, 1999). Since primary and permanent enamel are naturally brittle and fragile, they can easily cracked, especially along the enamel prisms that should be avoided (Shimada & others, 1999; Munechika & others, 1984). When conducting a micro-shear bond test, trimming is not a necessary step and preparing small specimens is so simple that multiple samples can be easily made (Senawongse & others, 2002; Shimada & others, 1999; Shimada, Yamaguchi & Tagami, 2002).

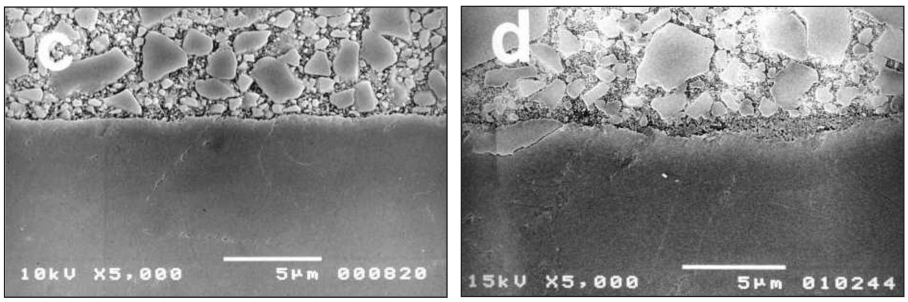
In this study, a micro-shear bond test was performed on primary enamel and the results were compared with results with permanent enamel. There was no statistically significant difference in bonding between primary and permanent enamel, which is different from previous studies of bonding performance to primary dentin (Salama & Tao, 1991; Bordin-Aykroyd & others, 1992; El Kalla & García-Godoy, 1998; Senawongse & others, 2002). Another interesting aspect of the results from this study was the minimal variation of the bond strengths, which demonstrates the reliability of bonding to primary or permanent enamel. In contrast, results from the SEM observations indicated that primary enamel was more reactive to acid conditioning than permanent enamel, which is similar to the result that primary dentin was responsive to acid etching (El Kalla & García-Godoy, 1998; Senawongse & others, 2002; Olmez & others, 1998; Nör & others, 1996). Thickness of the bonded interface after phosphoric acid etching was significantly greater in primary teeth, as seen in Figure 4b. The reasons for this phenomenon are not understood, but differences in chemical composition, micromorphology or chemical reactivity of the enamel may be contributing factors (Hirayama, 1990).

In this study, the self-etching primer system exhibited high strengths to bonded enamel in spite of its mild etching effect. Bonding to enamel is achieved by micromechanical adhesion resulting from the diffusion of resin monomers into the treated enamel and polymerization of resin creating a hybrid-like layer in the enamel (Nakabayashi & others, 1982; Kanemura & others, 1999; Shinchi & others, 2000). The length of resin tags has been shown to contribute little to the bond strength of resin to enamel and bonding is mainly attributable to the ability of the resin to penetrate between the enamel crystallites and rods (Kanemura & others, 1999; Shinchi & others, 2000). Consequently, in the case of

Figure 4. *SEM images of adhesive interfaces.*



(a) SEM image of Shingle Bond adhesion to permanent tooth enamel. Bonding resin flows and interlocks to the interprismatic and intercrystalline spaces. The resin infiltration into the etched enamel is approximately 3 μm in depth, and the etched zone is approximately 10 μm in depth.
(b) SEM image of Single Bond adhesion to primary tooth enamel. Mechanical interlocking of resin and enamel can be observed. The resin infiltration into the etched enamel is approximately 12 μm in depth.



(c) SEM image of Clearfil SE Bond adhesion to permanent tooth enamel. Superficial crystalline apatite was partially separated. The enamel-resin hybrid-like layer is approximately 1 μm in depth.
(d) SEM image of Clearfil SE Bond adhesion to primary tooth enamel. The difference from (c) is not clear. The enamel-resin hybrid-like layer is approximately 1 μm in depth.

enamel, the thickness of the hybrid-like layer appears to provide little influence on bonding. Probably, the resin monomers adequately penetrate into the etched surface of primary and permanent enamel and a deficiency in resin penetration into etched enamel does not occur in a manner similar to etched dentin (Kanemura & others, 1999; Shinchi & others, 2000).

Resin composites shrink as they polymerize, and contraction stresses increase within the resin (Davidson & others, 1984). An adequate bond to the tooth structure would reduce marginal microleakage, bacterial penetration that leads to recurrent decay, post-operative sensitivity and the possibility of pulpal inflammation (Brännström & Nyborg, 1973; Nakabayashi & others, 1982). To be effective, a bonding agent needs to achieve a strong, immediate bond between the tooth and the restorative material. With composites, bonding agents must resist polymerization contraction forces so that microscopic gaps can be minimized (Davidson & others, 1984). In this study, it became clear that bonding of current adhesive systems to primary enamel was almost the same as that to permanent enamel. Nevertheless, because primary enamel is thin, it is doubtful whether primary enamel can overcome the polymerization shrinkage stress of resin and preserve adhesive restorations without any undesirable changes. Therefore, failures of resin restorations in primary teeth are still a common problem, so that finding effective bonding processes can present a difficult challenge to pediatric dentists (Salama & Tao, 1991; Bordin-Aykroyd & others, 1992; El Kalla & García-Godoy, 1998; Senawongse & others, 2002). It is highly likely that the poor performance of adhesive restorations on primary dentition occurs because of poorer bonding to the dentin surface (Salama & Tao, 1991; Bordin-Aykroyd & others, 1992; El Kalla & García-Godoy, 1998; Senawongse & others, 2002). The results of the SEM observations also suggested a shorter application time for the phosphoric acid gel or the self-etching primer in primary enamel may be sufficient to create an etched surface similar to that seen in permanent enamel. The development of a new method or protocol for improved bonding to primary dentin may give dentists the chance to improve patient treatment.

CONCLUSIONS

Although the relatively intensive action of acid etching of primary enamel was observed, the bonding performance of either a self-etching primer system or a one-bottle adhesive was nearly similar to permanent enamel.

(Received 1 October 2001)

References

Bordin-Aykroyd S, Sefton J & Davies EH (1992) *In vitro* bond strength of three current dentin adhesives to primary and permanent teeth *Dental Materials* **8(2)** 74-78.

Brännström M & Nyborg H (1973) Cavity treatment with a microbicidal fluoride solution: Growth of bacteria and effect on the pulp Journal of *Prosthetic Dentistry* **30(3)** 303-310.

Davidson CL, de Gee AJ & Feilzer A (1984) The competition between the composite-dentin bond strength and the polymerization contraction stress *Journal of Dental Research* **63(12)** 1396-1399.

El Kalla IH & García-Godoy F (1998) Bond strength and interfacial micromorphology of four adhesive systems in primary and permanent molars *Journal of Dentistry for Children* **65(3)** 169-176.

Hirayama A (1990) Experimental analytical electron microscopic studies on the quantitative analysis of elemental concentrations in biological thin specimens and its application to dental science *Shika Gakuho* **90(8)** 1019-1036.

Kanca J (1992) Resin bonding to wet substrate. Bonding to dentin *Quintessence International* **23(1)** 39-41.

Kanemura N, Sano H & Tagami J (1999) Tensile bond strength to and SEM evaluation of ground and intact enamel surfaces *Journal of Dentistry* **27(7)** 523-530.

Munechika T, Suzuki K, Nishiyama M, Ohashi M & Horie K (1984) A comparison of the tensile bond strengths of composite resins to longitudinal and transverse sections of enamel prisms in human teeth *Journal of Dental Research* **63(8)** 1079-1082.

Nakabayashi N, Kojima K & Masuhara E (1982) The promotion of adhesion by the infiltration of monomers into tooth substrates *Journal of Biomedical Materials Research* **16(3)** 265-273.

Nör JE, Feigal RJ, Dennison JB & Edwards CA (1996) Dentin bonding: SEM comparison of the resin-dentin interface in primary and permanent teeth *Journal of Dental Research* **75(6**) 1396-1403.

Olmez A, Oztas N, Basak F & Erdal S (1998) Comparison of the resin-dentin interface in primary and permanent teeth *The Journal of Clinical Pediatric Dentistry* **22(4)** 293-298.

Salama F & Tao L (1991) Comparison of Gluma bond strength to primary vs permanent teeth *Pediatric Dentistry* **13(3)** 163-166.

Sano H, Shono T, Sonoda H, Takatsu T, Ciucchi B, Carvalho R & Pashley DH (1994) Relationship between surface area for adhesion and tensile bond strength—evaluation of a micro-tensile bond test *Dental Materials* **10(4)** 236-240.

Sano H, Takatsu T, Ciucchi B, Horner JA, Matthews WG & Pashley DH (1995) Nanoleakage: leakage within the hybrid layer *Operative Dentistry* **20(1)** 18-25.

Senawongse P, Harnirattisai C, Shimada Y & Tagami J (2002) Micro-shear bond strength of current adhesive systems on deciduous dentin *Journal of Dentistry* (in press).

Shimada Y, Antonucci JM, Schumacher GE, McDouough WG & Tagami J (1999) Effects of regional tooth structure and sectioning orientation on micro-shear bond strength. Tagami J, Toledano M, Prati C ed Advanced adhesive dentistry 3rd International Kuraray symposium Kuraray Co Ltd 91-103.

Shimada Y, Yamaguchi S & Tagami J (2002) Micro-shear bond strength of dual-cured resin cement to glass ceramics *Dental Materials* (in press).

Shinchi MJ, Soma K & Nakabayashi N (2000) The effect of phosphoric acid concentration on resin tag length and bond strength of a photo-cured resin to acid-etched enamel *Dental Materials* **16(5)** 324-329.

Watanabe I, Nakabayashi N & Pashley DH (1994) Bonding to ground dentin by a Phenyl-P self-etching primer *Journal of Dental Research* **73(6)** 1212-1220.

©Operative Dentistry, 2002, **27**, 410-417

Curing Light Intensity Effects on Wear Resistance of Two Resin Composites

AJ St-Georges • EJ Swift, Jr
JY Thompson • HO Heymann

Clinical Relevance

Curing resin composites using high-intensity lights might reduce the wear resistance of the materials.

SUMMARY

This in vitro **study evaluated the wear resistance of resin composite polymerized using four different light-curing systems. For this, a well-defined cylindrical cavity preparation (4.0 mm in diameter x 3.0 mm in depth) was made in a ceramic block (n=4 per material/light condition). Uncured material, either a universal hybrid composite (Herculite XRV) or a flowable hybrid composite (Revolution Formula 2), was packed and light-cured from the top surface only with one of the four light-curing units: 1) a conventional quartz-tungsten-halogen light, 2) a soft-start light, 3) an argon-ion laser or 4) a plasma-arc curing light. After storing the specimens in deionized water at 37°C for 24 hours, the excess cured material was ground through successive grits up to a final 1200-grit SiC abrasive. The specimens were placed in deionized water at 37°C for an additional 24 hours. Wear simulation was performed using a four-station Leinfelder-type three-body wear device. A slurry of water and unplasticized polymethylmethacrylate beads, simulating an artificial food bolus, was placed on the surface of each resin-composite-restored ceramic block. The entire cycling procedure was carried out 400,000 times. Impressions of each resin composite surface were taken with polyvinylsiloxane and epoxy replicas were made. Wear analyses were conducted by generating tracings across the worn surface of epoxy replicas using profilometer scans. For the universal hybrid composite and the flowable hybrid composite, the lowest wear occurred in specimens that were cured using the conventional quartz-tungsten-halogen light, and the highest wear was detected on those specimens made using the argon-ion laser. For both resin composites, the mean wear for specimens cured using the argon-ion laser was significantly higher than that of the specimens cured with the three other lights, which were statistically similar.**

*Annie J St-Georges, DMD, MS, assistant professor, Department of Restorative Dentistry, University of Montreal

Edward J Swift, Jr, DMD, MS, professor and chair, Department of Operative Dentistry, University of North Carolina

Jeffrey Y Thompson, PhD, associate professor, Department of Operative Dentistry, University of North Carolina

Harald O Heymann, DDS, MEd, professor and graduate program director, Department of Operative Dentistry, University of North Carolina

*Reprint request: University of Montreal, Faculty of Dental Medicine, CP 6128, succursale Centre-Ville, Montreal (Quebec), H3C 3J7; e-mail: annie.st-georges@umontreal.ca

INTRODUCTION

Since their early use in the 1960s, resin composites have been studied extensively *in vitro* and *in vivo* to overcome one major problem, wear (Phillips & others, 1971; Lutz & others, 1984; Wendt & Leinfelder, 1994; Perry & others, 2000). Wear is defined as loss of material from a surface caused by a mechanical action alone or through a combination of chemical and mechanical action (Anusavice, 1996). The first generation of resin composites had substantial occlusal and proximal wear in Class I and II restorations (Phillips & others, 1972; Leinfelder & others, 1980). Thermal and mechanical stresses and chemical degradation of the resin matrix were potential factors in the failure of self-cured resin composite restorations (Leinfelder & others, 1980). Moreover, inadequate mixing of the two-component system resulted in a non-uniform microstructure and incorporation of internal porosity that contributed to the disappointing clinical results of chemically-cured resin composites (Wilder, May & Leinfelder, 1983). For the next generation of resin composites, those activated with ultraviolet (UV) light, modifications, such as a more hydrophobic resin matrix, decreased particle size and reduced wear coefficient between the filler particles and the resin matrix, contributed to increased wear resistance under clinical conditions (Wilder & others, 1983). Also, the method of polymerization itself, the use of UV light instead of the mixing method, reduced the incorporation of voids and air bubbles in the resin composite and allowed a continuous polymerization process (Wilder & others, 1983; Wilder & others, 1999; Lutz & others, 1984). During this time, UV light-cured resin composites showed improvement in terms of wear resistance but were still not considered a suitable substitute for amalgam (Wilder & others, 1983; Lutz & others, 1984). Currently, visible light-cured (VLC) resin composites are well accepted as restorative materials, and their use as posterior resin composites is indicated for small to moderate-sized Class I and Class II restorations (ADA Council on Scientific Affairs, 1998). Modification of the type, shape and size of the fillers, as well as the resin matrix and the coupling agent between these two components, have allowed VLC resin composites to reach acceptable *in vivo* wear resistance (Willems & others, 1993; Wendt & Leinfelder, 1994; Rasmusson & Lundin, 1995; Leinfelder & Suzuki, 1999). Also, it was demonstrated that the rate of wear tends to decrease over time, leveling off after three to five years (Tyas & Wassenaar, 1991; Freilich & others, 1992; Wilder & others, 1999). Some studies have shown that clinical wear of some VLC resin composites is comparable to that of amalgam restorations (Willems & others, 1993; Hu, Marquis & Shortall, 1999). However, this comparison may be misleading because occlusal dental amalgams do wear (Lutz & Krejci, 1994), but the wear is gradually compensated by continuing expansion of the restoration, which is not the case with resin composites (Bayne, Heymann & Swift, 1994).

Dental practitioners must consider the different challenges associated with using resin composites as restorative materials in posterior teeth. The direct adhesive procedure is technique-sensitive and requires considerably more time than conventional amalgam restorations (Wilder, Bayne & Heymann, 1996). Etching and bonding the tooth structure, incremental placement and polymerization of each resin composite layer, contouring and polishing are multiple steps that add time to the procedure. To obtain acceptable restorations with optimal physical properties and clinical performance, dentists must not only be meticulous but they must also choose the appropriate type of light and polymerization technique (Koliniotou-Kubia & Jacobsen, 1990; Nomoto, Uchida & Hirasawa, 1994; Harris, Jacobsen & O'Doherty, 1999; Brackett, Haisch & Covey, 2000). In recent years, a multitude of choices for light-activation have become available (Mills, 1995; Mehl, Hickel & Kunzelmann, 1997; Kanca & Suh, 1999; Hofmann & others, 2000; Bouschlicher, Rueggeberg & Boyer, 2000). For all curing sources (quartz-tungsten-halogen [QTH] light, plasma-arc curing [PAC] light, and argon-ion laser) and techniques (continuous medium-intensity, continuous high-intensity, continuous low-to-high intensity and discontinuous low-intensity), there is a philosophy that the clinician should understand (Rueggeberg, 1999). At first glance, high-intensity lights such as the high-intensity QTH light, PAC light or argon-ion laser are attractive due to the potential for faster polymerization of the resin composite, which reduces chair time (Kelsey & others, 1989; Blankenau & others, 1991; Cobb & others, 1996; Vargas & others, 1998). However, studies have shown that not all high-intensity lights are able to produce comparable physical properties as those obtained with conventional QTH light (Burgess & others, 1999; Peutzfeldt, Sahafi & Asmussen, 2000). For some resin composites with photoinitiators other than camphoroquinone, using these high-intensity lights may result in inadequate polymerization (Hofmann & others, 2000).

High-intensity lights have intensity output greater than 1000 mW/cm^2 and can cure resin composites in 1 to 20 seconds depending on the shade of the resin composite (*Clinical Research Associates Newsletter*, 2000). Because the polymerization process is shortened, there is a possibility for the final polymer molecule to be compromised as to structure and ultimate molecular weight, thereby resulting in lower wear resistance (Rueggeberg, 1999). This study evaluated and compared the *in vitro* wear of two resin composites, a universal hybrid composite and a flowable hybrid composite, polymerized using four different light-curing units. The null hypothesis was that resin composites polymerized with high-intensity lights demonstrate no more wear than resin composites polymerized with a conventional QTH light.

METHODS AND MATERIALS

Herculite XRV (Kerr Corporation, Orange, CA 92867, USA), a universal hybrid composite, and Revolution Formula 2 (Kerr Corporation), a flowable hybrid composite, were used in this study. Both types of resin composite were used to evaluate whether the wear resistance of the flowable hybrid composite would be affected in a similar manner as the more highly filled universal hybrid composite using different light-curing techniques. Although their use is not recommended on occlusal surfaces except for very conservative restorations, a flowable composite was included in the study for its potential to be more sensitive to the different type of polymerization because of its higher resin content. Table 1 provides detailed information about shade, filler content, average particle size and batch numbers for both resin composites. Four different light-curing units were used and are listed in Table 2. Table 3 shows the exposure time and the energy density (J/cm^2) of each light used to polymerize the resin composite specimens.

Wear simulation was performed using a four-station Leinfelder-type wear device. For each station, a well-defined cylindrical cavity preparation was made in a ceramic block (Dicor MGC, Dentsply/Caulk, Milford, DE 19963, USA). The dimension of each cavity preparation was 4.0 mm in diameter and 3.0 mm in depth (the depth of cure of the A1 shade of each of the composites evaluated in this study was measured and exceeded 3.0 mm). To clean debris from the drilling inside the prepared cavities, the blocks were placed in an ultrasonic device for five minutes. The internal walls of the cavities were coated with a thin layer of silane agent and gently air dried. Uncured material of each resin composite was packed and slightly overfilled into the simulated cavity preparation. A Mylar strip was placed above the ceramic block and the resin composite was pressed flat using a flat metal block. The specimens were light cured from the top surface only using the conditions listed in Table 3. After storing the specimens in deionized water at 37°C for 24 hours, the excess cured material was ground through successive grits up to a final 1200-grit SiC abrasive so that a continuous smooth surface existed across the filled simulated cavity preparation. A well defined and uniform baseline sur-

Table 1

Materials	Manufacturer	Shade	Filler Content (by volume)	Average Particle Size (Microns)	Batch #
Herculite XRV	Kerr Corporation, Orange, CA 92867	Enamel A-1	59%	0.6	003936
Revolution Formula 2	Kerr Corporation, Orange, CA 92867	A-1	41%	0.6	004152

Table 2: *Light-Curing Units Used in the Study*

Curing Units	Manufacturers	Classification	Diameter of the Tip Used(mm)	Intensity (mW/cm^2)
Spectrum 800*	Dentsply/Caulk Milford, DE 19963	Conventional QTH	8	550
Elipar Trilight*	3M ESPE St Paul, MN 55144	Soft-start QTH	8	20 seconds: 100-850 + 20 seconds: 850
Virtuoso◊	Den-Mat Corporation Santa Maria, CA 93455	PAC	6	1980
Accucure 3000*	LaserMed Salt Lake City, UT 84088	Argon-ion laser	12**	725♦ 600#

** Intensity values were measured using Curing Radiometer, model 100 (Demetron Research Corporation, Danbury, CT 06810).*
◊ Intensity value was measured using Coltolux Light Meter (Coltène/Whaledent, Mahwah, NJ 07430).
*** Spot size is 6 mm.*
♦ Used "Resin A" mode to polymerize Herculite XRV (universal hybrid composite).
 # Used "Flowable B" mode to polymerize Revolution Formula 2 (flowable hybrid composite).

Table 3: *Exposure Duration (seconds) and Energy Density (J/cm²) of Each Light Used to Polymerize the Universal Hybrid (UNI) and the Flowable Hybrid (FLO) Composite Specimens*

Light Curing Unit	Exposure Time (seconds)*		Energy Density† (J/cm²)	
	UNI	FLO	UNI	FLO
Conventional QTH	40	40	22	22
Soft-start**	40	40	19	19
PAC	3	5	6	10
Argon-ion laser	15•	15#	11	9

* *Polymerized the top surface of the specimen only*
** *Used ramp mode: 20 seconds 100-850 mW/cm² + 20 seconds 850 mW/cm²*
• *Used "Resin A" mode*
\# *Used "Flowable B" model*
† *Energy density =* $\frac{\text{Watts x Seconds}}{cm^2} = \frac{\text{Joules}}{cm^2} = (J/cm^2)$

Table 4: *Means Wear and Standard Deviations of the Universal Hybrid and the Flowable Hybrid Composites Polymerized with Four Different Lights (For each composite, the vertical line represents statistically equivalent means [p≥ 0.05])*

	Wear (400,000 cycles) (µm ± sd)	
Resin Composites **Light Groups**	**Universal**	**Flowable**
Conventional QTH	9.3 ± 2.9	14.2 ± 4.2
Soft-start	10.6 ± 3.8	18.2 ± 2.6
PAC	12.4 ± 4.0	14.8 ± 1.4
Argon-ion laser	17.8 ± 8.0	29.3 ± 2.7

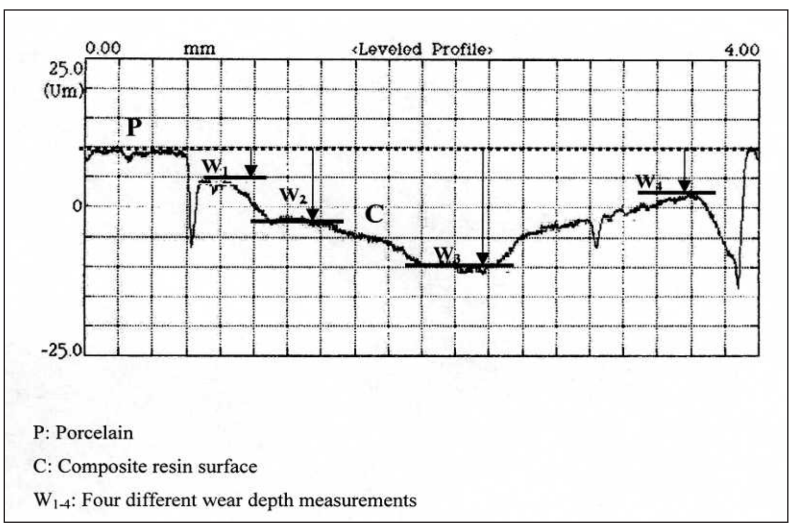


Figure 2. *Typical profilometric tracing of a specimen after generalized wear.*

face is necessary to achieve accurate measurement after wear testing due to the low wear rates exhibited by the composites used in this study. The specimens were placed in deionized water at 37°C for an additional

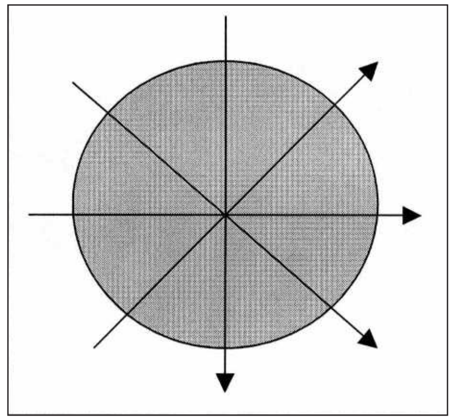


Figure 1. *Readings at every 45 degrees around the worn circular surface replicas for each epoxy specimen were done with a profilometer. Arrows in figure represent direction of surface scans.*

24 hours. Four specimens of each material/ light condition were tested.

The entire assembly that holds the ceramic blocks was encased in a water bath. A slurry of water and unplasticized polymethylmethacrylate (PMMA) beads averaging 44 µm in diameter was placed on the surface of each restored ceramic block. The water bath was filled with room temperature deionized water. The PMMA beads served as an artificial food bolus during the masticatory cycle. Each assembly was placed under a flat-planed 8.0-mm diameter polyacetal (Delrin) stylus and centered so that the stylus covered the resin composite specimen and 2 mm of the adjacent ceramic surface. At a rate of 1.2 times per second, each stylus was vertically loaded onto the restored surface under a load of 75 N. As soon as the maximum load was achieved, each stylus rotated clockwise 30 degrees, counter-rotated, then moved vertically up into its original position. The entire cycling procedure was carried out 400,000 times. Two impressions of each resin composite specimen were taken at the completion of the 400,000 cycles with polyvinylsiloxane impression material. The first impression taken after the wear process served to debrede the surface and was discarded. The second was used to determine quantitatively the actual loss of material from the occlusal surface in micrometers. An epoxy cast (positive) made from the impression was used for profilometer scans (Surfanalyzer Model 5000, Federal Products Co, Providence, RI 02940, USA). Wear analysis was conducted by generating tracings across the surface of the worn surface replicas. For each specimen, four profilometric tracings of the surface were made,

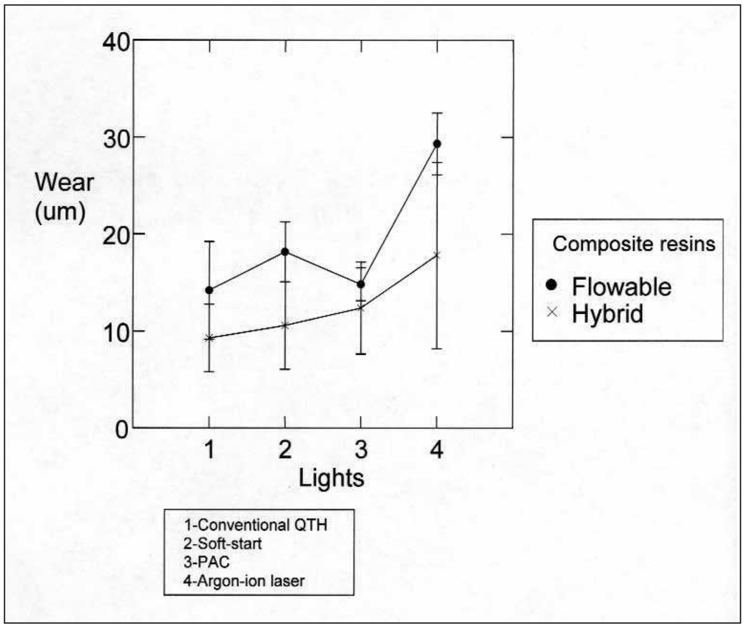


Figure 3. *Means wear (mm) and standard deviations of the universal hybrid and the flowable hybrid composites cured with four different lights.*

producing readings at every 45 degrees around the circular specimen (Figure 1). For each profilometric tracing, four points were determined (Figure 2) and composite wear depth was calculated using the porcelain border as the reference surface. For each specimen, mean wear was obtained from the four measurements and was used to calculate one mean wear value for each group (n=4/group). The data were subjected to a two-way ANOVA test (SYSTAT version 10) with the independent variables being the lights and the resin composites. A post-hoc test on lights was done using Tukey's HSD to protect against type II errors. The tests were performed at a 5% ($p \leq 0.05$) level of significance.

RESULTS

Means and standard deviations for wear of all material/light groups are shown in Table 4 and Figure 3. For the universal hybrid composite and the flowable hybrid composite, the lowest wear occurred in specimens that were cured using the conventional QTH light, with mean values of 9.3 ± 2.9 µm and 14.2 ± 4.2 µm, respectively. The highest wear was detected on those specimens polymerized using the argon-ion laser, with mean values of 17.8 ± 8.0 µm and 29.3 ± 2.7 µm, respectively. The two-way ANOVA shows that the interaction between the resin composites and the lights was not statistically significant (p=0.18). With all the lights, the flowable hybrid composite had more wear than the universal hybrid composite (p=0.0001). Finally, the specimens polymerized using the argon-ion laser had significantly more wear (p<0.0001) than the one polymerized using the other lights.

DISCUSSION

It is clear that wear is only one parameter that influences the clinical service of posterior resin composites. Other properties, such as polymerization shrinkage, may be more influenced by curing mode. However, wear of resin composites is still a concern, and it was decided to evaluate the effect of different lights-curing units on this property. Over the years, understanding resin composite wear rates and wear mechanisms has improved tremendously. A considerable amount of research on wear has been done to overcome what has long been a major problem related to posterior resin composites. It is now known that different events and mechanisms are involved with wear of posterior resin composites. The different events can be categorized in terms of where the wear occurs. Five basic types of resin composite wear have been described (Bayne & others, 1994; Sturdevant & others, 1995). Contact-free area wear (CFA) is produced by the food bolus, while occlusal contact area wear (OCA) occurs at centric holding contacts. The sliding motion of tooth contact during mastication produces functional contact area wear (FCA). Proximal contact area wear (PCA) occurs during minor tooth motion permitted by the periodontal ligament. Finally, toothbrush abrasion (TBA) is produced by the dentifrice or toothbrush bristles during oral hygiene procedures (Bayne & others, 1994). Of the five types, CFA wear has been extensively studied *in vitro* (Leinfelder & others, 1991; Suzuki & others, 1995; Condon & Ferracane, 1996; Leinfelder & Suzuki, 1999; Perry & others, 2000) and *in vivo* (Freilich & others, 1992; Willems & others, 1993; Wendt & Leinfelder, 1994). For small resin composite restorations, CFA is probably responsible for most of the wear clinically (Bayne & others, 1994). Therefore, in this study, CFA wear was simulated.

Several factors can contribute to wear of posterior resin composite. Among them are: material characteristics, preparation design, intraoral location, operator ability and patient characteristics such as diet, oral hygiene and fluoride history (Wilder & others, 1996). Moreover, filler particle size and shape (Suzuki & others, 1995) and monomer system used in the matrix (Asmussen, 1985) are important factors as well. Another element that might be added to the list due to its potential to affect the polymer's final structure is the photo-polymerization technique. It has been speculated that high-intensity light may negatively affect the formation of high molecular weight polymer chains and cross-linking during the polymerization (Rueggeberg, 1999; Albers, 2000) and, therefore, may affect the wear resistance and physical properties of resin composites.

Although clinical trials are the best method to predict the performance of a resin composite, the drawbacks are that they are expensive and the sponsors do not want to wait for the long-term results. Therefore, laboratory-based wear-simulation machines have been developed and improved to a point where they can predict clinical wear fairly well (Condon & Ferracane, 1996; Leinfelder & Suzuki, 1999). Previous studies (Leinfelder, Beaudreau & Mazer, 1989; Leinfelder & others, 1991; Leinfelder & Broome, 1994; Leinfelder & Suzuki, 1999) have demonstrated excellent agreement between wear data obtained from simulations on the Leinfelder-type three-body wear device and clinical research results. Three-body wear is generated by the food bolus during mastication (Leinfelder & Suzuki, 1999).

In vitro wear data from resin composites exposed to 400,000 cycles of the three-body Leinfelder wear system are comparable to the *in vivo* results of resin composite restorations evaluated after a two-year (Leinfelder & Broome, 1994) to three-year (Leinfelder & Suzuki, 1999) period of clinical wear. In this study, the universal hybrid and flowable hybrid composite specimens demonstrated means wear ranging between 9.3 to 17.8 µm and 14.2 to 29.5 µm, respectively. For the universal hybrid composite, an average annual wear rate of about 15 µm was estimated from a five-year clinical study (Wisniewski, Leinfelder & Isenberg, 1991). The extrapolation of this number to a two-year period gives a wear rate of 30 µm. The mean wear values obtained in this study for the universal hybrid composite fall into this range and can therefore be considered reasonable.

For both resin composites polymerized with the soft-start light, mean wear values were equivalent to those achieved with the conventional QTH light. These results indicate that with the ramp-cure technique, an adequate degree of polymerization is achievable, eliminating the possibility of under-cure that is sometimes associated with the use of a lower initial intensity.

Using high-output light sources reduces chairside exposure time while producing properties equivalent to those that would be realized if longer exposure with conventional QTH mode are used (Rueggeberg, Ergle & Mettenburg, 2000). For the PAC light, such a reduction of time, while providing equivalent wear, was realized in this study. However, this was not the case for the argon-ion laser. For both resin composites, the argon-ion laser produced significantly higher mean wear values than those achieved by the conventional QTH light. The wear of the universal hybrid composite polymerized with the argon-ion laser was significantly higher by 1.4 to 1.9 times than the other three universal hybrid/light groups. The same situation occurred for the flowable hybrid composite for which the mean wear of specimens polymerized with the argon-ion laser was significantly higher by 1.6 to 2.1 times than the three other groups. These results contradict the results of a study by Glasspoole & others (1990) that showed no significant difference in wear for resin composite polymerized with visible light and the argon laser when measured *in vitro* by profilometry in a three-body abrasion machine. Two possible explanations might account for the results obtained using the argon-ion laser in the current study. First, the 15-second exposure might be too short to provide thorough polymerization of the resin matrix. To increase the degree of conversion and possibly the wear resistance of resin composite cured with an argon-ion laser, longer exposure times should be investigated with further research. The second possible explanation is based on the rationale that high-intensity or "fast lights" can dramatically affect the extent of cross-linking and the polymer chain size formed and therefore affect the wear resistance of the material. During the initial stages of polymerization, the polymer being formed tends to be linear. Significant cross-linking occurs in the later stages of cure (Rueggeberg, 1999). With high-intensity lights, fast curing times are provided, which might yield inadequate development of cross-linked polymer network and therefore, affect the resin matrix quality of the resin composite.

Interestingly, with the use of the PAC light, which had the highest output intensity, resin composite specimens demonstrated similar wear values compared to those polymerized with the conventional QTH light. In this study, the hypothesis that high-intensity lights can affect the final structure of the resin matrix was not proven with the use of the PAC light. The reason that the PAC light did not adversely affect the wear resistance of both resin composites, as the argon-ion laser did, is difficult to explain. It could be that the spectral emission peak of the PAC light coincides with the absorbance peak of the camphoroquinone (CQ) present in both resin composites. In fact, the suitability of the PAC light as a curing device depends on which photoinitiators the resin composites contain. For resin composites containing photoinitiators that absorb shorter wavelengths (370-450 nm), mechanical properties can be adversely affected if the photo-polymerization device is a PAC light because the absorption spectrum of the photoinitiators does not overlap with the narrow wavelength produced by the PAC light (Hofmann & others, 2000). Another important feature to consider with the use of a PAC light is the exposure time. In a study by Hofmann & others (2000), it was observed that irradiation of the resin composite by only one cycle of three seconds failed to produce adequate mechanical properties. In this study, as recommended by the manufacturer of the PAC light, a three-second exposure time for the universal hybrid composite and a five-second exposure time for the flowable hybrid composite was used and the results were not significantly different from the one obtained with the use of the conventional QTH light.

So far, no data are available on the effects of different curing techniques, such as the ones used in this study, on resin composite wear. Therefore, comparing the results of this study with others is not possible. Further research using resin composites with different resin systems and filler content is needed. Other types of resin composites may be more or less photosensitive and may provide different curing patterns with the lights tested.

CONCLUSIONS

Based on the results of this study, the null hypothesis was rejected. The wear resistance of both resin composites was significantly affected by one of the two high-intensity lights used. For the universal hybrid and flowable hybrid composites tested, the argon-ion laser had an adverse effect on wear resistance, producing specimens that displayed the highest mean wear for both resin composites. The other high-intensity light, the PAC light, with the highest output intensity and shorter exposure duration, resulted in no significant adverse effects on resin composite wear compared to the conventional QTH light. The clinical relevance of the findings in this research remains to be determined. Clinically, the ability of resin composites to flow during the curing process may be limited by the preparation design, the fact that they are bonded to the tooth structure and the choice of high-intensity light as a curing device. All these factors can influence the polymerization of the resin matrix, which might have different characteristics than the one found in the resin composite specimens tested in this study. Therefore, resin composite restorations polymerized with high-intensity lights might show different wear resistance than the resin composite specimens in the current *in vitro* study. *In vivo* research is needed to determine whether rapid polymerization of resin composites with a PAC light or argon-ion laser clinically compromise the wear resistance of the final restoration.

Acknowledgements

This study was supported by Kerr Corporation, Orange, CA 92867, USA. The resin composites and light-curing units used in this project were donated by their respective manufacturers. The authors thank Dr Aldridge D Wilder, Jr and Dr Thomas L Ziemiecki for their help with reviewing the manuscript, which is based on a thesis submitted to the graduate faculty, University of North Carolina at Chapel Hill, in partial fulfillment of the requirements for the MS degree. The authors thank Pierre H Rompré from the Université de Montréal for his assistance with statistical analysis.

(Received 3 October 2001)

References

Albers HF (2000) Resin polymerization *ADEPT Report* **6** 1-16.

American Dental Association, Council on Scientific Affairs; American Dental Association, Council on Dental Benefit Programs (1998) Statement on posterior resin-based composites *Journal of the American Dental Association* **129** 1627-1628.

Anusavice K (1996) *Phillips' Science of Dental Materials* 10th Edition, WB Saunders Co pp 273-299.

Asmussen E (1985) Clinical relevance of physical, chemical, and bonding properties of composite resins *Operative Dentistry* **10(2)** 61-73.

Bayne SC, Heymann HO & Swift EJ Jr (1994) Update on dental composite restorations *Journal of the American Dental Association* **125(6)** 687-701.

Blankenau RJ, Kelsey WP, Powell GL, Shearer GO, Barkmeier WW & Cavel WT (1991) Degree of composite resin polymerization with visible light and argon laser *American Journal of Dentistry* **4(1)** 40-42.

Bouschlicher MR, Rueggeberg FA & Boyer DB (2000) Effect of stepped light intensity on polymerization force and conversion in a photoactivated composite *Journal of Esthetic Dentistry* **12(1)** 23-32.

Brackett WW, Haisch LD & Covey DA (2000) Effect of plasma arc curing on the microleakage of Class V resin-based composite restorations *American Journal of Dentistry* **13(3)** 121-122.

Burgess JO, DeGoes M, Walker R & Ripps AH (1999) An evaluation of four light-curing units comparing soft and hard curing *Practical Periodontics & Aesthetic Dentistry* **11(1)** 125-132.

Clinical Research Associates (2000) Resin curing lights *CRA Newsletter* **24** 1-4.

Cobb DS, Vargas MA & Rundle T (1996) Physical properties of composites cured with conventional light or argon laser *American Journal of Dentistry* **9(5)** 199-202.

Condon JR & Ferracane JL (1996) Evaluation of composite wear with a new multi-mode oral wear simulator *Dental Materials* **12(4)** 218-226.

Freilich MA, Goldberg AJ, Gilpatrick RO & Simonsen RJ (1992) Three-year occlusal wear of posterior composite restorations *Dental Materials* **8(4)** 224-228.

Glasspoole EA, Blankenau RJ, Barkmeier WW & Powell GL (1990) Wear rates of argon laser and visible light polymerized resins *Journal of Dental Research* **69** Abstract #143 p 126.

Harris JS, Jacobsen PH & O'Doherty DM (1999) The effect of curing light intensity and test temperature on the dynamic mechanical properties of two polymer composites *Journal of Oral Rehabilitation* **26(8)** 635-639.

Hofmann N, Hugo B, Schubert K & Klaiber B (2000) Comparison between a plasma arc light source and conventional halogen curing units regarding flexural strength, modulus, and hardness of photoactivated resin composites *Clinical Oral Investigations* **4(3)** 140-147.

Hu X, Marquis PM & Shortall AC (1999) Two-body *in vitro* wear study of some current dental composites and amalgams *The Journal of Prosthetic Dentistry* **82(2)** 214-220.

Kanca J & Suh BI (1999) Pulse activation: Reducing resin-based composite contraction stresses at the enamel cavosurface margins *American Journal of Dentistry* **12(3)** 107-112.

Kelsey WP, Blankenau RJ, Powell GL, Barkmeier WW, Cavel WT & Whisenant BK (1989) Enhancement of physical properties of resin restorative materials by laser polymerization *Lasers in Surgery and Medicine* **9(6)** 623-627.

Koliniotou-Kubia E & Jacobsen PH (1990) The effect of irradiation time on the physical properties of light-cured resins *Clinical Materials* **6(1)** 21-28.

Leinfelder KF, Sluder TB, Santos JFF & Wall J (1980) Five-year clinical evaluation of anterior and posterior restorations of composite resins *Operative Dentistry* **3** 276-281.

Leinfelder KF, Beaudreau RW & Mazer RB (1989) An *in vitro* device for predicting clinical wear *Quintessence International* **20(10)** 755-761.

Leinfelder KF, Mirshahidi M, Cury C & O'Neal W (1991) An *in vitro* wear device for determining wear of posterior composites *Journal of Dental Research* **70** Abstract #636 p 345.

Leinfelder KF & Broome JC (1994) *In vitro* and *in vivo* evaluation of a new universal composite resin *Journal of Esthetic Dentistry* **6(4)** 177-183.

Leinfelder KF & Suzuki S (1999) *In vitro* wear device for determining posterior composite wear *Journal of the American Dental Association* **130(9)** 1347-1353.

Lutz F, Phillips RW, Roulet JF & Setcos JC (1984) *In vivo* and *in vitro* wear of potential posterior composites *Journal of Dental Research* **63(6)** 914-920.

Lutz F & Krejci I (1994) Mesio-occlusodistal amalgam restorations: Quantitative *in viv*o data up to 4 years. A database for the development of amalgam substitutes *Quintessence International* **25(3)** 185-190.

Mehl A, Hickel R & Kunzelmann KH (1997) Physical properties and gap formation of light-cured composites with and without 'softstart-polymerization' *Journal of Dentistry* **25(3-4)** 321-330.

Mills RW (1995) Blue light emitting diodes-another method of light curing? *British Dental Journal* **178(5)** 169.

Nomoto R, Uchida K & Hirasawa T (1994) Effect of light intensity on polymerization of light-cured composite resins *Dental Materials Journal* **13(2)** 198-205.

Perry R, Kugel G, Kunzelmann KH, Flessa HP & Estafan D (2000) Composite restoration wear analysis: conventional method vs three-dimensional laser digitizer *Journal of the American Dental Association* **131(10)** 1472-1477.

Peutzfeldt A, Sahafi A & Asmussen E (2000) Characterization of resin composites polymerized with plasma arc curing units *Dental Materials* **16(5)** 330-336.

Phillips RW, Avery DR, Mehra R, Swartz ML & McCune RJ (1971) One-year observations on a composite resin for Class II restorations *The Journal of Prosthetic Dentistry* **26(1)** 68-77.

Phillips RW, Avery DR, Mehra R, Swartz ML & McCune RJ (1972) Observations of a composite resin for Class II restorations: Two-year report *The Journal of Prosthetic Dentistry* **28(2)** 164-169.

Rasmusson CG & Lundin SA (1995) Class II restorations in six different posterior composite resins: Five-year results *Swedish Dental Journal* **19(5)** 173-182.

Rueggeberg FA (1999) Contemporary issues in photocuring *Compendium of Continuing Education in Dentistry* **(Supplement)20(25)** S4-S15.

Rueggeberg FA, Ergle JW & Mettenburg DJ (2000) Polymerization depths of contemporary light-curing units using microhardness *Journal of Esthetic Dentistry* **12** 340-349.

Sturdevant CM, Roberson TM, Heymann HO & Sturdevant JR (1995) Dental Materials In: *The Art and Science of Operative Dentistry* 3rd edition St Louis Mosby pp 257-258.

Suzuki S, Leinfelder KF, Kawai K & Tsuchitani Y (1995) Effect of particle variation on wear rates of posterior composites *American Journal of Dentistry* **8(4)** 173-178.

Tyas MJ & Wassenaar P (1991) Clinical evaluation of four composite resins in posterior teeth Five-year results *Australian Dental Journal* **36(5)** 369-373.

Vargas MA, Cobb DS & Schmit JL (1998) Polymerization of composite resins: Argon laser vs conventional light *Operative Dentistry* **23(2)** 87-93.

Wendt SL Jr & Leinfelder KF (1994) Clinical evaluation of a posterior resin composite: 3-year results *American Journal of Dentistry* **7(4)** 207-211.

Wilder AD, May KN & Leinfelder KF (1983) Three year clinical study of UV cured composite resins in posterior teeth *The Journal of Prosthetic Dentistry* **50(1)** 26-30.

Wilder AD, Bayne SC & Heymann HO (1996) Long-term clinical performance of direct posterior composites *Academy of Dental Materials* 151-166.

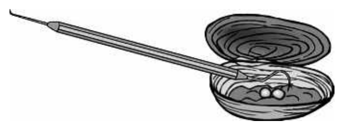
Wilder AD, May KN, Bayne SC, Taylor DF & Leinfelder KF (1999) Seventeen-year clinical study of ultraviolet-cured posterior composite Class I and II restorations *Journal of Esthetic Dentistry* **11(3)** 135-142.

Willems G, Lambrechts P, Braem M & Vanherle G (1993) Three-year follow-up of five posterior composites: *In vivo* wear *Journal of Dentistry* **21(2)** 74-78.

Wisniewski JF, Leinfelder KF & Isenberg BP (1991) Five-year clinical evaluation of a fine particle posterior composite resin *Journal of Dental Research* **70** Abstract #1526 p 457.

Departments

Operative Pearls



Please submit your own clinical tips and techniques to share with your colleagues. Send "pearls" and/or comments on this section via FAX (317) 278-4900 or e-mail to: editor@jopdent.org.

A QUICK, "NO-POLISH" TECHNIQUE FOR SMALL COMPOSITE REPAIRS

Contributed by:
James S Knight, DDS
MUSC College of Dental Medicine
Department of General Dentistry
Charleston, SC

Introduction

Occasionally, dentists must provide a small repair to an otherwise serviceable composite restoration due to a marginal defect, chip fracture, void or unesthetic stained area. During finishing and polishing, it is sometimes difficult to avoid damaging the adjacent composite, thus complicating what should be a relatively simple procedure. A technique is presented which, in many cases, may eliminate the finish/polish step in the placement of these small composite applications.

Procedure

1) The area is prepared, etched for 10-15 seconds to provide a clean, reactive composite surface, then rinsed and dried.
2) Bonding adhesive is sparingly applied with a small brush while making an effort to minimize excess adhesive beyond the prepared area. The adhesive is thinned with dry air and light-polymerized.
3) A visible light cured microhybrid composite material is placed into the preparation and shaped with a hand instrument to approximate desired final contour.
4) A soft sable brush, lightly moistened with adhesive, is used to smooth the composite surface and margins to achieve a "finished" result.
5) Apply a layer of an oxygen barrier solution such as DeOx (Ultradent Products, Inc, South Jordan, UT 84095, USA) or plain glycerin over the composite
6) Polymerize with a visible light source.
7) Rinse off the oxygen barrier solution. The resulting composite surface is hard and smooth with little or no finishing and polishing required.

Discussion

This technique has many applications where small composite restorations are indicated. The critical step is the smoothing and finishing of the unpolymerized composite with the sable brush prior to placing the oxygen barrier solution. Since the superficial outer layer of resin is protected from contact with air, it polymerizes to produce a "glaze-like" finish. A microhybrid composite with small filler particles is most suitable for this technique because it is more easily manipulated with the brush to facilitate a smooth, polished surface. With practice, the technique may be used successfully with other types of composites as well.

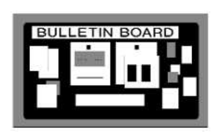
Conclusions

This technique offers a simple and predictable way to minimize or even eliminate the need for post-cure finishing and polishing of small composite restorations. It provides a way to place a finished restoration without risking damage to the surrounding tooth or restorative material.

Disclaimer

The author has no proprietary, financial, professional or other personal interest of any kind in any of the products or the manufacturer mentioned in this article.

Announcements



Funding for Students' Research in Operative Dentistry

Undergraduate dental students wanting to carry out research related to Operative Dentistry may apply for a Ralph Phillips Research Award, sponsored by the Founder's Fund of the Academy of Operative Dentistry.

The application should consist of a protocol (and 15 copies) outlining the background, aim/hypothesis to be tested, the methodology to be employed, a time schedule and the expected outcome of the study. The protocol should not exceed three double-spaced type-written pages and a budget page (including where the funds should be sent provided the Award is granted). The budget may not exceed $5,000.

If an abstract, based on the research and acknowledging support from the Academy of Operative Dentistry, is accepted for presentation at the IADR/AADR meeting in 2003, additional travel funds not exceeding $1,000 will be made available to the recipient.

A Faculty Advisor should be named, and he/she should co-sign the application. The application must be submitted by December 15, 2002 to:

Academy of Operative Dentistry,
Research Committee
c/o Dr Ivar A Mjör, Chairman
UFCD, Box 100415
Gainesville, FL 32610

Applications may also be submitted by e-mail to: imjor@dental.ufl.edu followed by one signed original mailed to the above address. Award recipients will be announced during the Annual Meeting of the Academy of Operative Dentistry, February 26-28, 2003.

Operative Dentistry Home Page

We hope all our readers will take advantage of the information available by accessing our Internet home page. Our address is: **http://www.jopdent.org/**

The home page contains a search engine and buttons that, hopefully, will lead you to answers to any questions you may have related to Operative Dentistry. These are:

Journal: leads to information on the Editorial Staff and Editorial Board; a complete index of journal volumes; a compilation of direct gold references; highlights of the current, next, and future issues, as well as a more detailed look at published Editorials and Clinical Pearls.

Subscribe: leads to complete information on subscription rates; purchasing back issues, reprints, and bound volumes; and subscription and change of address forms.

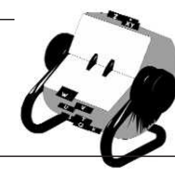
Affiliates: provides links to the American Academy of Gold Foil Operators, the Academy of Operative Dentistry, the AADS-Operative Section, and our Corporate Sponsors. In addition, membership applications for the journal's parent academies are available for downloading.

News: announcements of interest to our readers, including meeting information, advertised faculty positions, and upcoming CE courses.

Authors: complete instructions for contributors to the journal.

Reviewers: password-protected link for our Editorial Board to submit manuscript reviews electronically.

Corporate Sponsorship



Operative Dentistry invites dental manufacturers that share our commitment to timely publication of research and clinical articles relevant to the discipline of restorative dentistry to become Corporate Sponsors of the journal. Operative Dentistry is distributed in 54 countries with more than 1,800 subscribers. The cost of sponsorship is U.S. $3,000.00 per year (January through December). Sponsors will be recognized by having their company logo displayed on a special page in each issue of the journal for the duration of their sponsorship.

A complimentary subscription to Operative Dentistry will be sent to the corporate contact person, and the sponsor's logo will appear in the Corporate Sponsors section of our web page, where it will act as a link to their company's website. Interested parties should contact the Editor at Operative Dentistry, 1121 West Michigan Street, Indianapolis, IN 46202-5186; phone: (317) 278-4800; fax: (317) 278-4900; e-mail: editor@jopdent.org; URL: http://www.jopdent.org/

Instructions to Contributors

Correspondence

Send manuscripts and correspondence regarding manuscripts to Dr Michael A Cochran, Editor, *Operative Dentistry*, Indiana University School of Dentistry, Room S411, 1121 W Michigan St, Indpls, IN 46202-5186; phone (317) 278-4800; fax (317) 278-4900; e-mail: editor@jopdent.org; URL: http://www.jopdent.org/.

Exclusive Publication

All material submitted for publication must be submitted exclusively to *Operative Dentistry*. Manuscripts not following the form outlined below may be returned for correction and resubmission.

Manuscripts

❐ Submit an original typed manuscript and three copies. The manuscript should include a short title for running headlines. Any identifying information (author's names, etc) should be on a separate page and not a part of the manuscript. Authors with English as a second language should consider having their manuscript reviewed for grammar, syntax and punctuation prior to submission.

❐ Submit a computer disk and identify the operating system (Macintosh or IBM-compatible) and the word processing program used.

❐ Identify the corresponding author and provide a complete address, fax number and e-mail address.

❐ Supply complete names, degrees, titles and affiliations for all authors (include addresses that are different from the corresponding author's).

❐ Proprietary names of equipment, instruments and materials should be followed in parenthesis by the name and address, of the source or manufacturer.

❐ Research (clinical and laboratory) papers MUST include a one sentence Clinical Relevance statement, as well as a Summary, Introduction, Methods and Materials, Results, Discussion and Conclusions section. Funding other than material supply must be stated.

❐ Clinical Technique/Case Report papers should contain at least the following: Purpose, Description of Technique or Solution, along with materials and potential problems and a Summary outlining advantages and disadvantages.

❐ Type double-spaced, including references, and leave margins of at least 3 cm (1 inch). Spelling should conform to the *American Heritage Dictionary of the English Language*. SI (Système International) units are preferred for scientific measurement, but traditional units are acceptable.

❐ The editor reserves the right to make literary corrections.

Illustrations

Please do NOT submit any illustrations or graphs in Microsoft Power Point or Word format. They will not be accepted.

❐ Submit four copies of each illustration.

❐ Line drawings should be in India ink or its equivalent on heavy white paper, card or tracing velum. All lettering must be of professional quality, legible against its background and remain proportionally legible if reduced. Type legends on separate sheets.

❐ Photographs should be on glossy paper with a maximum size of 15x20 cm (6x8 inches). For best reproduction, a print should be one-third larger than its reproduced size.

❐ On the back of each illustration indicate lightly in pencil the top and the number of the figure ONLY (no names). Where relevant, state staining technique(s) and the magnification of the prints. Obtain written consent from holders of copyright to republish any illustrations published elsewhere.

❐ Illustrations may also be supplied on floppy disk, Zip disk or CD as TIFF files with a minimum resolution of 300 dpi (dots per inch) for grayscale and 1200 dpi for color.

❐ Photographs become the property of *Operative Dentistry*.

Tables and Graphs

❐ Submit tables and graphs on sheets separate from the text.

❐ Graphs are to be submitted with any lettering proportional to their size, with their horizontal and vertical axes values displayed.

❐ Data for constructing graphs MUST be provided with the manuscript in a spreadsheet (Excel) or word processing format on computer disk.

❐ Graphs may be supplied on floppy disk, Zip disk or CD as TIFF files with a minimum resolution of 300 dpi. or as Microsoft Excel files.

References

❐ References must be arranged in alphabetical order by authors' names at the end of the article, with the year of publication placed in parentheses immediately after the author's name. This is followed by the full journal title (no abbreviations and in italics), the full subject title, volume and issue numbers and first and last pages.

❐ In the text, cite references by giving the author and, in parentheses, the date: Smith (1975) found…; or, by placing both name and date in parentheses: It was found…(Smith & Brown, 1975; Jones, 1974).

❐ When an article being cited has three authors, include the names of all of the authors the first time the article is cited; subsequently, use the form (Brown & others, 1975). Four or more authors should always be cited in the text as (Jones & others, 1975). In the References section, always list all the authors.

❐ If reference is made to more than one article by the same author and is published in the same year, the articles should be identified by a letter (a, b) following the date, both in the text and in the list of references.

❐ Book titles should be followed by the publication address and the name of the publisher.

Reprints

Reprints of any article, report or letter can be ordered through the editorial office.

OPERATIVE DENTISTRY
CORPORATE SPONSORS

These Dental Manufacturers have joined *Operative Dentistry* in our commitment to publish quality dental literature in a timely manner. We thank them for their support.

SDI
SOUTHERN DENTAL INDUSTRIES

Den-Mat®

IVOCLAR NORTH AMERICA, INC.
IVOCLAR • VIVADENT • WILLIAMS

DENTSPLY
CAULK

BISCO
Specialist In Adhesive and Composite Technology
Bringing Science to the Art of Dentistry™

UP® ULTRADENT

3M ESPE

sds Kerr
SYBRON DENTAL SPECIALTIES

J. MORITA
USA INC.

Please view the Corporate Sponsors Page at our website (http://www.jopdent.org) for direct links to these companies.

JULY/AUGUST 2002 • VOLUME 27 • NUMBER 4 • 317-420

©OPERATIVE DENTISTRY, Inc.

EDITORIAL

CLINICAL RESEARCH

LABORATORY RESEARCH

DEPARTMENTS

10-9385
Operative Dentistry
Indiana University School of Dentistry, Rm. S411
1121 West Michigan Street
Indianapolis, IN 46202-5186 USA