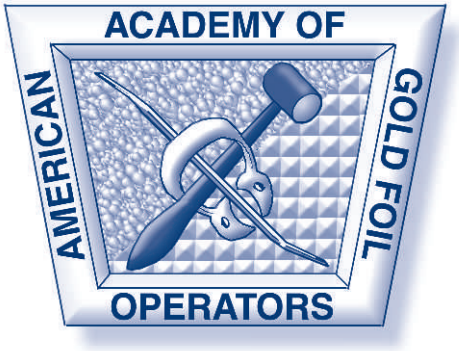
OPERATIVE DENTISTRY



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

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A Clinical Comparison of Two Cements for Levels of Post-operative Sensitivity in a Practice-based Setting

T Hilton •D Hilton
R Randall • JL Ferracane

Clinical Relevance

Both conventional and resin-modified glass ionomer luting cements provide equally low levels of post-operative sensitivity when used to cement either all metal or porcelain fused-to-metal crowns.

SUMMARY

This study compared the post-operative results of cementing full crowns (all metal or PFM) with either a conventional (Fuji I, GC; n=102) or a resin modified GI luting cement (Rely X, 3M/ESPE; n=107). Methods: Ten private practitioners fabricated 209 crowns using standardized preparation/luting criteria and randomly assigned cements. Patients self-reported temperature and biting sensitivity, on a 0-10 scale at 24 hours, one week, one month and three months post-cementation. Data were analyzed using *t*-tests, confirmatory Mann-Whitney tests and Pearson correlations, with a significance level of $p \leq 0.05$. Results: Of all patients, 50.7% reported any sensitivity at any time period. Mean sensitivity for all patients on the 10-point scale was 0.52 for temperature and 0.23 for biting. Cements did not differ in cold or biting sensitivity at any time. There were many significant (though low) correlations between the sensitivity measures and age (inverse relationship) and dentin area of preparation (direct). The practice-based format provided a viable alternative to performing clinical research.

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INTRODUCTION

For years, sensitivity following indirect restoration cementation has been reported. It is a problem that has plagued patients and proven problematic to dentists, leading clinicians, manufacturers and researchers to search for a solution that would limit its occurrence. Post-operative sensitivity rates have varied widely in clinical studies, ranging from a low of 3.1%, to a high of 32% (Åberg, van Dijken & Olofsson, 1994; Jokstad & Mjör, 1996; Dahl & others, 1986; Brackett & Metz,

1992; Johnson, Powell & DeRouen, 1993). Sensitivity intensity tends to vary and is typically reported to be mild to moderate in level (Johnson & others, 1993). Rarely is the post-operative pain so intense or prolonged that endodontic therapy is required. Endodontic therapy resulting from pain due to crown cementation has been reported to be less than 3% (Jokstad & Mjör, 1996; Brackett & Metz, 1992; Johnson & others, 1993). While post-operative discomfort tends to be short-term, that is, several weeks or less (Jokstad & Mjör, 1996; Brackett & Metz, 1992; Åberg & others, 1994), some cases of prolonged sensitivity of up to a year or longer have been reported (Jokstad & Mjör, 1996; Dahl & others, 1986).

The type of cement apparently has only a minor impact on post-operative luting sensitivity. Zinc phosphate has been in clinical use for more than a century (Baldwin, 1897) and has demonstrated a long-term clinical track record of success (Ferracane, 1995). As a result, zinc phosphate cement is often considered the "gold standard" against which other cements are evaluated. However, zinc phosphate suffers from several drawbacks, including a low pH immediately after mixing and at cementation, no fluoride release and no chemical adhesion to tooth structure (Craig, 1997). Another cement that is commonly used for indirect restoration luting is glass ionomer. This cement also has a low pH at cementation but does release fluoride and provides a chemical bond to tooth structure (Craig, 1997). In side-by-side clinical comparisons, both cements have provided comparable clinical performance and incidence of post-operative sensitivity (Johnson & others, 1993; Jokstad & Mjör, 1996). Johnson and others (1993) found a significantly higher incidence of post-operative temperature sensitivity with zinc phosphate at two weeks, but by three months, there was no difference between the two.

A number of causes for post-operative discomfort have been suggested, including overly aggressive tooth preparation, poor provisional restorations, desiccation of the preparation prior to cementation and removal of the protective smear layer prior to cementation (Johnson & others, 1993). Another concern for practitioners is *in-vivo* dissolution of the luting agent (Phillips & others, 1987). Both glass ionomer and zinc phosphate are subject to dissolution in an aqueous environment (Craig, 1997; Phillips & others, 1987). Recently, a new product has been introduced as a luting agent, the resin-modified glass ionomer. This material retains the benefits of the conventional formulation of glass ionomer, namely, the consistent fluoride release and chemical adhesion to tooth structure, while having a higher pH upon mixing and less solubility in fluids (Craig, 1997). It is hoped that the improved properties of the resin-modified version of glass ionomer will improve clinical performance and decrease post-cementation sensitivity. This study compared the sensitivity of teeth following cementation of full crowns with conventional glass ionomer and resin-modified glass ionomer cements. It also evaluated the effectiveness of using a practice-based research model to accomplish oral health clinical research.

METHODS AND MATERIALS

The study protocol was reviewed and approved by the Oregon Health and Science University Institutional Review Board.

Selection of Clinicians

Ten experienced dentists (range 10 to 46 years in general private practice) participated in the study. The use of multiple practitioners in the normal private practice setting was used to ensure maximum external validity of the results. All the clinicians were knowledgeable practitioners with extensive experience in crown-and-bridge dentistry. The clinicians participated in a training session to familiarize them with the protocol for the study and to standardize the procedures and techniques to be utilized.

Selection of Patients

Subjects were selected from the patient population of the individual providers participating in the study. Patients required the placement of a full crown as part of their treatment plan. Inclusion criteria included individuals of any age in generally good health; the need for one crown on a vital tooth that was in occlusion and had at least one proximal contact; was free from active periodontal disease and a minimum of 1/3 of the crown preparation had to be natural tooth structure (teeth where almost the entire coronal aspect of the tooth consisted of a build-up were excluded). The patient could not require restoration of an adjacent tooth during the duration of the study (three months). All patients received, read and signed a written informed consent form prior to being entered into the study.

The study was designed to have approximately 100 crowns in each experimental group, for a total of 200 crowns. Allowance was made for an approximate 10% patient loss during the course of the study, thus, the initial study goal was approximately 220 crowns.

Clinical and Laboratory Procedures

General guidelines regarding tooth preparation were agreed upon in advance, so that there was some degree of conformity regarding the amount of tooth reduction. Full metal restorations generally had 0.7-1.0 mm of axial reduction with either a chamfer or bevel margin and 1.0-1.5 mm of occlusal reduction. Porcelain fused to metal (PFM) crowns had 0.7-1.0 mm of axial reduction for those portions of the crown that remained in metal, while having 1.2-1.5 mm reduction for those areas that were veneered with porcelain. Gingival finish lines for PFM crowns were chamfer or bevel for metal margins

or butt joint if the crown had a porcelain margin. Occlusal reduction for PFM crowns were 1.0-1.5 mm for those areas that were in metal and 1.5-2.0 mm occlusal reduction if the occlusal aspect was veneered with porcelain. Clinicians used a high-speed handpiece with air-water coolant spray for tooth preparation. Impressions and the provisional crown were made using the clinicians' usual materials and techniques. The provisional crown was luted in place with a non-eugenol containing temporary cement. All-ceramic crowns were not included in the study.

Clinicians used their normal laboratory to have the crowns fabricated. They were encouraged to use the same laboratory for all crowns fabricated for the study.

At the time of crown cementation, the clinicians opened an envelope containing a number generated from a random-number assignment program. This number informed the practitioner which cement should be used to lute the crown in place, either conventional glass ionomer cement (Fuji I, GC Corporation, Alsip, IL, USA) or resin-modified glass ionomer (Rely X luting cement, 3M/ESPE, St Paul, MN, USA). Providers used the manufacturer's recommended procedure for luting the crowns.

Preparation Appointment Data

Tooth #: _____

Pre-op vitality testing: Cold +/- Electric Pulp Test: __/__

Pre-op patient-reported temperature sensitivity: ___ (on a scale of 0-10, with 0=no pain, 10 worst imaginable)

Pre-op patient-reported biting sensitivity: ___ (on a scale of 0-10)

Crown Type: ❑ PFM ❑ All metal

Reason for crown procedure: _____

Impression cord used: Yes/No Type: _____ Hemostatic agent used: Yes/No ____ Type: _____

% of crown preparation that is dentin (as opposed to restoration/build-up):

0 – 1/3 1/3 – 2/3 2/3 – all

Cementation Appointment Data

Patient-reported temperature sensitivity with temporary crown: ___ (on a scale of 0-10)

Patient-reported biting sensitivity with temporary crown: ___ (on a scale of 0-10)

Anesthetic used for cementation: Yes/No

If tooth was not anesthetized, did the patient experience sensitivity at cementation? If yes, what was sensitivity level? _____ (on a scale of 0-10)

Cement type: Fuji I ____ Rely-X ____ Number from sheet in envelope _____

Any problems noted at cementation?

Comments:

Figure 1. *Preparation and cementation data.*

1. Are you experiencing any temperature sensitivity to the tooth on which you had the crown cemented yesterday? Yes/No

   If yes: Is it temperature sensitive to Hot? Yes/No If yes: On a scale of 0 -10 (0=no pain, 10 worst imaginable), how severe is the hot sensitivity? _____

   If yes, is it temperature sensitive to Cold? Yes/No If yes: On a scale of 0 -10 (0=no pain, 10 worst imaginable), how severe is the cold sensitivity? _____

2. Are you experiencing any biting sensitivity to the tooth on which you had the crown cemented yesterday? Yes/No

   If yes: On a scale of 0 -10 (0=no pain, 10 worst imaginable), how severe is the biting sensitivity today? _____

3. Additional comments/explanation:

Figure 2. *Post-Cementation data.*

Data Acquisition

The practitioners obtained the information shown in Figure 1 at the preparation and cementation appointments, including confirming tooth vitality either by cold test or electric pulp testing. This data and the patient consent form were faxed or mailed to the study coordinator upon completion. After cementation of a study crown, the practitioner informed the study coordinator so that the appropriate follow-up could be accomplished. Any post-operative complications of a study tooth that required the patient to return to the practitioner were also reported to the study coordinator.

The study coordinator contacted the patient by telephone at the following times: 24 hours, one week, one month and three months after luting the permanent crown. At those times, the post-cementation sensitivity

data shown in Figure 2 was completed by the study coordinator and placed into the study database. All pre- and post-operative sensitivity was patient-reported and a scale of 0 to 10, with 0 = no pain and 10 = worst imaginable pain was used. The patients were referred to their original practitioner if the telephone interview revealed that the patient was experiencing unusual or severe post-operative problems.

Follow-up

After all patients in the study were completed, all individual patient data forms and a summary spreadsheet of the results were thoroughly examined. All practitioners were then contacted by letter and asked to resolve discrepancies found during the review. In addition, the practitioners were requested to review the records of all patients who participated in the study to ensure that no exclusion criteria had occurred after crown cementation (for example, another restoration in the same sextant) or that no patient had returned for treatment of a study tooth during the study period. Phone follow-up was accomplished until all practitioners responded with the requested data. Upon receipt of this information, the final figures were compiled and subjected to statistical analysis.

Statistical Analysis

The null hypothesis tested was that the particular cement used would not differentially affect reported pain at any time following treatment.

Pain scores for the two different cement groups were compared separately for data collected at 24 hours, one week, one month and three months following treatment. While pain measurements were recorded on a 10-point scale, the actual distribution of recorded values indicated that some re-scaling was appropriate. With data maintained on the original 10-point scale and with n=100 per group, parametric test methods were applicable. Assuming a population effect size ($|\mu 1-\mu 2|/\sigma$) of 0.4, the power of this study was 80 in order to detect a difference between groups. With data treated as binary, power for chi-squared tests for differences in proportions depended on the particular pain rates and differences in the rates observed. With n=100 per group, power was 80 to detect differences in pain rates of 0.300 versus 0.127 and 0.400 versus 0.208.

The *t*-test for independent samples was the primary parametric statistical test method. However, several of the pre-cementation variables (percentage of the crown preparation that is dentin) were screened to determine if there was any correlation with the pain outcome variable. In this case, then, analysis of covariance was appropriate and increased statistical power. Similarly, covariates that existed with respect to a binary outcome were incorporated into a logistic regression.

RESULTS

A total of 210 patients and 213 teeth were initially enrolled in the study. Several study teeth were eliminated for violating the inclusion/exclusion criteria. In most cases, it was because other treatment was accomplished in the same quadrant. In one case, the crown placed was an all-ceramic crown rather than the required PFM or all-metal crown. In a few instances, the patients met all inclusion criteria for entrance into the study, but at some point during the three-month study period, they required other treatment in the same quadrant. In these cases, data prior to this other treatment being completed was used, but data after that point was not. One crown, a PFM on tooth #10 cemented with Fuji I, came off during the study period. Ultimately, 209 subjects successfully completed protocol requirements for inclusion into the study, although there were occasional losses (1.6% of all possible data points) of follow-up sensitivity measurements.

The primary dependent variable, cement type, was randomly assigned to subjects, while other potential factors were either uncontrolled or determined by the clinician. Table 1 shows that age, gender, crown type and preparation dentin area were balanced by cement-type treatment ($p>0.2$). It should be noted that of the 209 scores for the proportion of crown preparation that were dentin, there were only two values of 0 to 1/3. To simplify the analysis, these scores were recoded to 1/3 to 2/3 throughout the analysis.

Scores for sensitivity to heat, cold and biting, which were recorded after one day, one week, one month and three months, had predominantly "0" values (range 0-10). Because of distributional skew and associated inferential problems, several approaches to data consolidation and transformation were explored. For heat, cold and biting sensitivity, mean values at each time point were calculated and differences in means or medians across the four time periods were evaluated (by one-way repeated-measures ANOVA or the non-parametric

Table 1: *Demographics for Cement Groups*

		Age[a]		Gender[b]		Crown Type[b]		Prep Dentin Area[b]	
Cement	N	Mean	SD	Male	Female	PFM	All Metal	1/3-2/3	2/3-all
RelyX	106	52.3	10.8	56	50	59	47	26	80
Fuji	103	54.2	11.5	46	57	60	43	22	81

[a] *Independent sample* t-*test,* p>*0.2*
[b] *Chi-square for two independent proportions, all* p>*0.2*

Table 2: *Evaluations of Three Indexes of Heat, Cold and Biting Sensitivity*

Comparisons		Means (SD) of Within-Subject Mean Sensitivity			Means (SD) of Within-Subject Maximum Observed Sensitivity			N (absent/present) for Sensitivity at Any Time		
	n	Hot	Cold	Biting	Hot	Cold	Biting	Hot	Cold	Biting
Cement										
RelyX	106	0.71 (0.26)	0.76 (1.25)	0.21 (.059)	0.64 (1.47)	1.61 (2.42)	0.59 (1.46)	84/22	64/42	85/21
Fuji	103	0.34 (0.69)	0.76 (1.13)	0.30 (0.69)	0.94 (1.77)	1.63 (2.11)	0.77 (1.65)	73/30	52/51	77/26
Gender										
Male	102	0.28 (0.66)	0.75 (1.16)	0.24 (0.53)	0.66 (1.34)	1.55 (2.07)	0.69 (1.33)	78/24	56/46	74/28
Female	107	0.32 (0.74)	0.77 (1.23)	0.27 (0.73)	0.92 (1.86)	1.69 (2.46)	0.27 (1.75)	79/28	60/47	88/19
Crown										
PFM	119	**0.18 (0.56)**	***0.46 (0.88)***	0.22 (0.61)	**0.51 (1.32)**	***1.15 (1.91)***	0.57 (1.41)	**98/21**	***78/41***	95/24
All Metal	90	**0.46 (0.82)**	***1.15 (1.43)***	0.30 (0.68)	**1.32 (1.91)**	***2.24 (2.55)***	0.82 (1.73)	**59/31**	***38/52***	67/23
Prep Area										
1/3-2/3	48	0.15 (0.40)	**0.41 (0.92)**	0.13 (0.35)	0.50 (1.34)	**0.94 (2.01)**	0.40 (0.98)	40/8	**35/13**	39/9
2/3-all	161	0.34 (0.76)	**0.92 (1.24)**	0.29 (0.70)	0.88 (1.70)	**1.83 (2.31)**	0.76 (1.68)	117/44	**81/80**	123/38
R with Age	209	-0.120	***-0.265***	-0.127	-0.139	***-0.289***	-0.122	-0.128	**-0.204**	-0.161

p*<0.05*, p*<.01* and p*<.001* for italics, bold and italics-bold, respectively.

Table 3: *Crown Type, Age, Preparation Dentin Area and Cement Type as Pain Predictors*

	Crown Type	Age	Preparation Dentin Area	Cement Type
Cold	0.001	0.001	0.002	ns
Hot	0.006	0.049	ns	ns
Biting	ns	0.019	ns	ns

p *values shown, ns = not significant*

Friedman test, respectively). The ANOVA *p*-values were smaller than those for the non-parametric tests but no *p* was less than 0.3. Therefore, the time variable was not further considered and three within-subject summary measures were constructed for each type of sensitivity: Mean sensitivity score over time, maximum sensitivity score observed over time and the binary classification of no observed sensitivity versus any observed sensitivity. Because there were some missing values, these statistics were computed on the basis of available data.

Table 2 shows these scores for several arrangements of the data. Forty-five statistical tests were conducted (four pair-wise groupings and one set of bivariate correlations by three summary measures by three types of sensitivity). Differences in the medians of mean and maximum scores, over time, were tested by the Mann-Whitney. Differences in the proportion of subjects that exhibited sensitivity were evaluated with Chi-square tests. The significance of correlations was determined by appropriate tests referencing the *t*-distribution. For pair-wise groupings, all three formations of the data yielded the same pattern of statistically significant results. Crown type influenced hot and cold sensitivity and preparation dentin area influenced cold sensitivity. Age was inversely associated with all sensitivity outcomes and to a statistically significant degree for (a) cold sensitivity and (b) heat sensitivity but only for maximum value and (c) biting sensitivity when defined as a binary outcome.

To evaluate the possible effects of imbalances on the significant results achieved by crown type, preparation dentin area and age (as an interval variable) and the lack of significance for cement type, these variables were used as predictors for the binary (absence or presence) hot, cold and biting sensitive outcomes using stepwise logistic regression. Due to the large number of zero values, logistic regression on each of the binary outcomes was considered more appropriate than linear regressions on the mean or maximum values. Table 3 summarizes these results. For hot sensitivity, crown type and age entered the model (with improvement Chi-square *p*-values of 0.006 and 0.049, respectively). For cold sensitivity, crown type (p=0.001), age (p=0.001)

and preparation dentin area (p=0.002) entered the model, and for biting sensitivity, only age (p=0.019) entered the model. These results generally confirm the univariate determinations of significance described in Table 2. Crown material, proportion dentin and age affect sensitivity under various circumstances, but there is no support in this study that gender or cement type substantially influenced sensitivity.

DISCUSSION

Ultimately, overall sensitivity scores were quite low for both cements, with sensitivity levels starting out low and staying low throughout the duration of the study. Figures 3 and 4 graphically depict this fact, showing the mean sensitivity scores for hot, cold and biting for Rely X and Fuji I, respectively. The highest mean sensitivity was for cold, which averaged 0.8/10 after 24 hours for both luting agents (0.9 for Rely X, 0.7 for Fuji I), and gradually decreased to approximately 0.6/10 (0.6 for both cements) by three months. The mean values for hot and biting were even lower. Fuji I demonstrated a slight, non-significant increase in hot and biting sensitivity from 24 hours to three months. Only two teeth, an all-metal crown on tooth #2 and a PFM crown on tooth #5, both cemented with Fuji I, ultimately required endodontic therapy within the time frame of the study. This is an endodontic rate of 1.0% for the study duration, falling well within the range noted in other studies (Jokstad & Mjör, 1996; Brackett & Metz, 1992; Johnson & others, 1993). While this study is limited by the fact that the survey duration is relatively short-term, there is little reason to expect from the literature that sensitivity will increase from this point. Indeed, it is considerably more likely that sensitivity will decrease in the future. Therefore, there is every reason to expect that the resin modified glass-ionomer cement should exhibit comparable clinical success in terms of low post-operative sensitivity to the well recognized standard established by conventional glass ionomer cements.

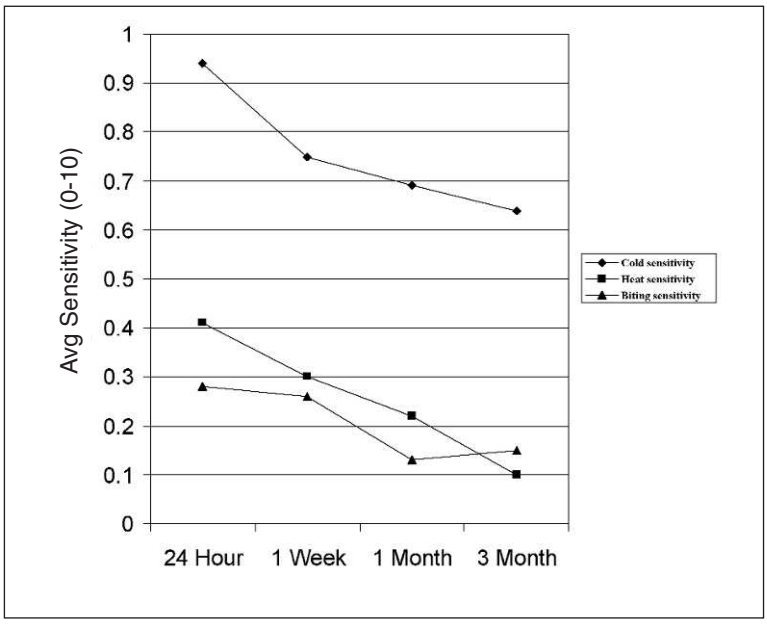

Figure 3. *Mean Sensitivity Values over time: Rely X.*

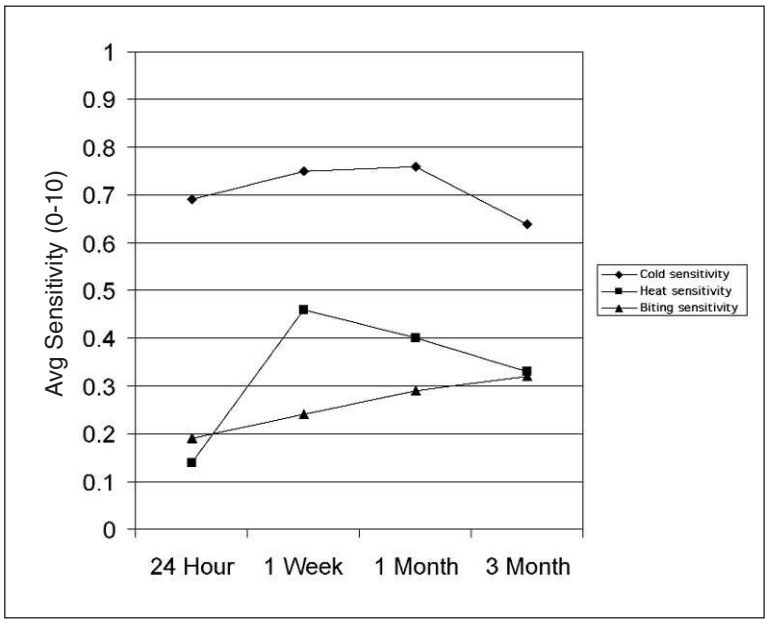

Figure 4. *Mean Sensitivity Values over time: Fuji I.*

The significant correlations found between various combinations of post-operative sensitivity and crown type, patient age and preparation dentin area can be explained on the basis of the hydrodynamic theory of pulpal pain. First proposed by Brännström (1984), this concept of pain transmission recognizes that there is a slow outward flow of dentin fluid through dentin tubules. Any stimulus that increases the fluid flow stimulates pain fibers within the dental pulp (Ahlquist & others, 1994). The dentin fluid would expand or contract on the basis of a temperature change. This would result in a compensatory rate of outward fluid flow that would be interpreted by the pulp as pain. In the case of crown type, all-metal crowns would more readily transmit temperature changes in the mouth to the underlying tooth structure than would PFM crowns. For example, Au-Ag-Pd alloy has a thermal conductivity of 300 (mcal/sec)/cm^2 ^{o}C/cm as compared to 2.4 (mcal/sec)/cm^2 ^{o}C/cm for feldspathic porcelain (O'Brien, 1997). It is reasonable to conclude that the ceramic covering the PFM crown would reduce temperature transmission to the crown preparation relative to an all metal crown, thereby reducing the amount of dentin fluid contraction or expansion that could cause pulpal pain.

Likewise, the significant correlation of dentin preparation area on cold sensitivity can be explained by the hydrodynamic theory. Increasing the dentin preparation area would increase the number of dentin tubules exposed and, therefore, the total volume of dentin fluid available to be affected by the transmission of cold temperature through the crown. Why dentin preparation area significantly affected cold sensitivity but not heat sensitivity is more difficult to explain. However, the average sensitivity level to heat was much lower overall at all time periods and, therefore, changes were more likely to be less and not of statistical significance.

Patient age significantly affected all three sensitivity measurements. Once more, the likely explanation lies with the hydrodynamic theory. Younger patients have larger pulps. Therefore, a typical crown preparation brings the vertical crown walls into closer proximity of the pulp. It is well known that dentin tubules are larger in diameter and occupy a greater proportion of dentin surface area, with permeability increasing as dentin approaches the pulp (Stanley, 1990; Pashley, 1990). Therefore, a greater volume of dentin fluid is going to be affected by any stimulus closer to the pulp vs farther away from the pulp. An additional factor regarding patient age is that older teeth tend to have more sclerotic and/or tertiary dentin formation (Stanley & others, 1983; Vasiliadis, Darling & Levers, 1983; Murray & others, 2000; Whittaker & Bakri, 1996). These dentin types often reduce or preclude dentin fluid flow (Pashley, 1996) and, therefore, any stimulus is less likely to alter pain transmission.

The use of the practice-based research protocol utilized in this study offered a number of benefits. It made it possible to address the shortcomings of clinical research as it is currently carried out. Controlled clinical trials are conducted primarily in university settings under very closely managed conditions. This scenario imparts the necessary scientific rigor to ensure that results are attributable to the independent variables. It helps to ensure that the study outcomes provide accurate and precise information about a new treatment, material or technique. These controlled clinical studies are most useful for determining the maximum potential of the treatment of interest. However, they do not duplicate how various procedures are performed in routine practice outside of this setting and, therefore, do not provide information about the typical outcomes to be expected within a practice-based population of clinicians. This discrepancy can significantly affect conclusions regarding oral health care outcomes (Jokstad, Mjör & Qvist, 1994; Wilder & others, 1999). Controlled clinical trials are very expensive, and therefore typically include too few patients to provide adequate statistical power. In addition, controlled clinical trials do not allow assessment of disease progression and treatment effects under normal *in situ* conditions in which dentistry is routinely practiced. Therefore, there is a need for practice-based clinical studies that can reach a large, diverse population, while maintaining an adequate level of control of the design and conduct of the study.

CONCLUSIONS

Within the limits of this study, the following conclusions are provided.

1. No differences in cold, heat or biting sensitivity over time were found for either cement.
2. There were no differences in any sensitivity category at any time period between the two cements.
3. All-metal crowns demonstrated greater temperature sensitivity, but not biting sensitivity, compared to PFM crowns.
4. Age is inversely correlated to all sensitivity measures, and preparation dentin surface area is directly related to all sensitivity measures, but only cold sensitivity is significant.
5. All-metal crowns, younger age and increased preparation dentin surface area are predictors of increased cold sensitivity.
6. All-metal crowns and younger age are predictors of increased heat sensitivity.
7. Younger age is a predictor of increased biting sensitivity.
8. Overall sensitivity with either cement was very low.
9. The Practice-based research protocol used in this study provided a precise, efficient alternative to institutionally based studies in oral health.

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Long-term Survival of Repaired Amalgams, Recemented Crowns and Gold Castings

RJ Smales • WS Hawthorne

Clinical Relevance

Repair, rather than replacement of defective amalgam restorations, can be a very effective treatment procedure over five years. However, the recementation of indirect restorations is a less effective procedure over the same time span.

SUMMARY

This retrospective longitudinal study compared the long-term survival rate of repaired versus replaced amalgam restorations and recemented crowns and gold castings versus non-recemented similar restorations. Private general dental practitioners treated adult subjects at three city practices. No significant survival differences were found between the repaired and replaced amalgams at five years, although the repaired amalgams showed higher failure rates by 10 years (p=0.37). However, there were significantly higher failures by five years for recemented crowns (p<0.001) and recemented gold castings (p=0.01) when compared with the initially cemented restorations. After 10 years, the repaired amalgams had survival rates of approximately 37 ± 15 (SEr) percent, recemented crowns 28 ± 15 (SEr) percent and recemented gold castings 42 ± 17 (SEr) percent.

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INTRODUCTION

Although several authors have advocated selective repair and refurbishment of defective restorations rather than their replacement (Barbakow & others, 1988; Ettinger, 1990; Mjör, 1993; Paterson & others, 1995; Cardoso, Baratieri & Ritter, 1999: Mjör & Gordan, 2002), there is scant long-term clinical evidence to support the effectiveness of these and related procedures (Özcan & Niedermeier, 2002). Clinical reports on the repair of restorations have focused on particular techniques, rather than on long-term performance following repairs (Finger, 1987; Carlson & others, 1990; Anderson, 1993; Denehy, Bouschlicher & Vargas, 1998; Latta & Barkmeier, 2000; Ahmad, 2002). Overwhelmingly, the investigation of restoration repairs has been based on *in vitro* studies. These usually involve examining either the bond strengths or microleakage of different restorative materials repaired using various surface preparation and adhesive methods. Most of these studies have reported significantly reduced bond strengths for aged repaired materials (Roeder, DeSchepper & Powers, 1991; Bapna & Mueller, 1993; Hadavi & others, 1993; Jamaluddin & Pearson, 1994; Nuckles, Draughn & Smith, 1994; Farid & Abdel-Mawla, 1995; Flores, Charlton & Evans, 1995; Shahdad & Kennedy, 1998; Yap, Quek & Kau, 1998; Shaffer, Charlton & Hermesch, 1998; Davis, 1999; Sau & others, 1999; Ozer & others, 2002). However, the

repair of non-carious marginal defects in aged amalgam restorations using low-viscosity resins resulted in significantly reduced *in vitro* microleakage (Cassin, Pearson & Picton, 1991; Roberts, Charlton & Murchison, 2001).

Far fewer *in vitro* studies have been conducted on the forces required to dislodge recemented indirect restorations. The use of zinc phosphate cement to recement metal crowns has been shown to result in a significant decrease over their initial cementation values (Felton, Kanoy & White, 1987; Ayad, Rosenstiel & Woelfel, 1998). Cutting access cavities in metal crowns for endodontic treatments also reduced their retention when zinc phosphate cement was used (McMullen, Himel & Sarkar, 1990; Mulvay & Abbott, 1996). However, when the access cavities were repaired with either amalgam or glass ionomer cement, the original crown retention values were significantly exceeded.

Because of the dearth of clinical information available on the survival of repaired amalgam and recemented indirect restorations, this study tests the null hypothesis that the long-term survival of such restorations is not significantly different from replaced amalgams and initially cemented indirect restorations.

METHODS AND MATERIALS

During 1992, restorative treatment data were obtained from the casenote records of 100 adult subjects who attended three centrally located large, long-established busy city practices in Adelaide, South Australia. The randomly selected subjects were required to have a continuous attendance history of at least 10 years for courses of restorative treatment provided by private general dental practitioners. The identities of all subjects and dentists were encoded for confidentiality. The University of Adelaide Committee on the Ethics of Human Experimentation approved the study.

Treatment data for amalgam restorations, crowns (gold, porcelain, metal-ceramic) and gold castings (inlays, onlays, partial veneers) from each course of treatment were transcribed from the casenote records onto serial odontograms for visual checking before being encoded into a computer database. The data were subjected to numerous error-checking procedures, and four subjects were recalled for detailed examinations to verify the accuracy of the casenote records and data transcriptions. The error incidence was 3.4%, where the dentists providing the treatment had not recorded one restoration placement and three restored surfaces.

A restoration was deemed to have failed when it was replaced, repaired (with amalgam in the case of amalgam restorations) or recemented. Treatment decisions were based on the clinical judgements of the individual dentists. When a sound restoration failed from an unrelated cause such as tooth extraction due to trauma or periodontal disease or from being incorporated into a larger restoration, it was censored in the life-table survival analysis. Survival estimates were performed using BMDP program IL (Dixon, 1990), with the probability level for statistical significance set at $p \leq 0.01$.

RESULTS

Subjects attended the same practice anywhere from 10 to more than 40 years in some instances. Table 1 shows the survival estimates for the restorations at 5, 10 and 15 years.

Although there was no statistically significant difference between the survival of replaced and repaired amalgams (p=0.37), approximately 63% of the replaced amalgams were still present at 10 years and 50% at 15 years, while only 37% of the repaired amalgams were still present at 10 years. However, there were very similar survival rates for both groups at five years. For both the crowns and gold castings, significantly lower survival rates were found for the recemented restorations than for the initially cemented restorations at all time periods ($p \leq 0.01$). Therefore, the null hypothesis was accepted for the amalgam restorations but rejected for the indirect restorations. The relatively few repaired amalgam and recemented indirect restorations and the wide variation in their survival times resulted in relatively large standard errors.

DISCUSSION

Long-established private practices offer a more stable, relevant environment than institutions for evaluating the long-term results of dental treatments. Many of the subjects in this study had regularly attended the same practice and used the same dentist for 20 years or longer. This situation, and the method of dentist remuneration (Mjör, Dahl & Moorhead, 2000; Burke & others, 2002), would be expected to lead to improved restoration survivals.

The amalgam restorations placed initially during this study had a cumulative mean survival of 27.4 ± 1.0 (SEr) years (Hawthorne, 1993). Many of the initial restorations, especially, would have been made from low-copper content alloys. The amalgam replacement restorations, as shown in Table 1, had a much lower cumulative mean survival of approximately 15 years. However, there were no statistically significant differences found between the survival rates of the original and replacement crowns (p=0.12) or gold castings (p=0.10), although the original restorations appeared to fare slightly better than the replacements (Hawthorne, 1993).

The advantages of repairing local defects include less sound tooth substance destroyed and less iatrogenic damage to adjacent proximal tooth surfaces, less risk to pulpal health and less discomfort and pain, and the

procedure being faster and less expensive than restoration replacement. However, there may be problems in achieving adequate access for removing secondary caries and placing the repair material. Radiographs may not detect the full extent of caries beneath metallic restorations, adjacent proximal root surfaces and gingival tissues may be damaged when attempting to remove cervical overhangs, the remaining tooth substance and the strength and retention of the repaired restoration may be compromised, shade matching may be less than ideal and the long-term cost-effectiveness of the procedure has not been determined. It is important to determine the reasons for restoration failure, the type and extent of failure and the quality of the restoration beyond the failure site before any local repairs are attempted (Mjör, 1993).

Table 1: *Percentage Survival Estimates for Restorations at Different Times*

Material (N)	5 Years	10 Years	15 Years
Amalgams			
Replaced (609)	78.9 (1.9)	62.8 (2.5)	49.9 (2.8)
Repaired (24)	76.1 (9.4)	37.2 (14.9)	—
		Mantel-Cox = 0.81, df = 1, p=0.37	
Crowns			
Initially cemented (264)	89.5 (2.1)	77.3 (3.2)	71.8 (3.8)
Recemented (14)	41.6 (14.8)	27.7 (15.0)	—
		Mantel-Cox = 33.28, df = 1, p<001*	
Gold castings			
Initially cemented (30)	83.3 (6.8)	72.9 (8.2)	45.1 (9.2)
Recemented (13)	56.4 (14.8)	42.3 (16.5)	—
		Mantel-Cox = 6.59, df = 1, p=0.01*	

N=restoration observations. Standard errors are shown in parentheses
**Statistically significant overall at the 1.0% probability level.*

Because of scant clinical evidence, there appears to be considerable uncertainty among dentists related to the appropriateness and expected longevity of repaired restorations (Blum & others, 2003). The authors have been able to locate only one relatively short-term clinical study on repaired restoration survival rates. After a mean observation period of approximately three years, intraoral repairs of metal-ceramic crown fractures showed a cumulative survival rate of 89% (Özcan & Niedermeier, 2002). Multiple repairs were required in approximately 10% of instances. In this study, many of the crowns and gold castings would have been cemented and recemented using zinc phosphate cement or glass ionomer cement. The former material has shown significantly decreased *in vitro* retention values for the recementation of metal crowns (Felton & others, 1987; Ayad & others, 1998), and the use of modern resin-based adhesive cements would be expected to lead to enhanced long-term survivals.

The primary reasons for the high replacement rates of restorations in general practice include secondary caries, bulk fracture of the material or tooth substance, marginal defects and color mismatch of tooth-colored materials (Mjör & Medina, 1993; Mjör, 1997; Mjör, Moorhead & Dahl, 2000). The attempted complete removal of bonded resin-based tooth-colored restorations especially has been shown to lead to significantly larger cavities, even though removal of the materials may be incomplete (Millar, Robinson & Davies, 1992; Hunter, Treasure & Hunter, 1995; Krejci, Lieber & Lutz, 1995; Gordan, 2001; Dörter, Yildiz & Erdemir, 2003). The complete removal of posterior amalgam and glass ionomer cement restorations has also been shown to result in increased cavity sizes, although to a much lesser extent and with faster, more complete removal of material (Elderton, 1977; Smith, 1992; Hunter & others, 1995; Krejci & others, 1995; Mjör & others, 1998). Clinical studies involving many general practitioners also show an increase in the number of restored tooth surfaces when many restorations are either replaced or recommended for replacement, much to the detriment of dental health (Cheetham, Makinson & Dawson, 1991; Brantley & others, 1995). Larger restorations have been shown to have higher failure rates compared to smaller ones (Smales, 1991; Hawthorne, 1993; Woods & others, 1994).

There is an obvious need for long-term clinical studies to be undertaken following the refurbishment, repair and recementation of different restorative materials using various methods. The detailed criteria required for such procedures (Mjör, 1993) and their cost-effectiveness still remain to be determined.

CONCLUSIONS

The findings from this long-term retrospective clinical study indicated that:

1. The repair of local defects in amalgam restorations is an effective alternative to restoration replacement, especially over five years.
2. The recementation of dislodged crowns and gold castings is less effective over five years.

Further long-term, controlled clinical studies are needed following the repair and recementation of different restorative materials to determine the detailed criteria required for using and the cost-effectiveness of these procedures.

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Clinical Evaluation of a Polyacid-modified Resin Composite-based Fissure Sealant: Two-year Results

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Clinical Relevance

Dyract Seal application to permanent molars in combination with invasive technique was effective in terms of retention and prevention of caries when compared to Delton FS+.

SUMMARY

A 24-month clinical study was carried out to evaluate and compare the retention rate, marginal integrity and caries preventing effects of a polyacid-modified resin composite based fissure sealant, Dyract Seal, to that of a resin based fluoride fissure sealant, Delton FS+. Fifty-three patients (27 female and 26 male), 7 to 10 years old, were included in the study. At baseline, a total of 192 permanent first molars were sealed with either fissure sealant (n=96, each), using invasive technique. The sealed teeth were evaluated at post-operative 3, 6, 12 and 24 months with respect to evaluation parameters. The data were analyzed with the Chi-Square tests where α=0.05. There were no statistically significant differences between fissure sealants as regards to retention and prevention of caries for all periods of the evaluation ($p>0.05$). However, regarding marginal integrity of the sealants, Delton FS+ gave significantly better results than Dyract Seal for the 3-, 6- and 12-month evaluations, respectively ($p<0.05$). In conclusion, the use of Dyract Seal on permanent molars with invasive technique was found to be clinically comparable to Delton FS+ for the 24-month evaluation period.

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INTRODUCTION

The prevalence of dental caries in most developed countries has declined in recent decades (Brunelle & Carlos, 1982; Kalsbeek & Verrips, 1990; Brown & Selwitz, 1995). However, the caries decline has not been uniform for all tooth surfaces, and the reduction of smooth surface caries has been more pronounced than for occlusal pit and fissure lesions (Ripa, 1985, 1993). According to the results of the 1986-87 NIDR survey of US schoolchildren, these sites accounted for more than 85% of the total caries experienced (Hicks & Flaitz, 1993). Considering that the occlusal surfaces comprise 12.5% of total tooth surfaces, this finding becomes more interesting (Waggoner & Siegal, 1996).

Pit-and-fissure sealants are the most effective means of reducing caries risk that arises from these sites (Simonsen, 1991). In order to maximize the caries-preventing effect of fissure sealants, fluoride incorporation into these materials has been considered. On permanent teeth, complete retention rates for fluoride fissure sealants has reported to vary between 77% to 96% for two years (do Rego & de Araujo, 1996; Carlsson, Petersson & Twetman, 1997; Boksman & Carson, 1998), 96% for three years (Vrbic, 1999) and 76.5% for four years (Lygidakis & Oulis, 1999).

Polyacid-modified resin composites (PMRC), introduced in the early 1990s, have been developed as a direct esthetic restorative material that combined the desirable properties of light-curing composites with those of fluoride-releasing glass-ionomer cements (Duke, 1999; Hse, Leung & Wei, 1999). It has become an important part of many dental practices throughout the world and has also enjoyed a growing interest from clinical and laboratory studies (Çehreli & Altay, 2000; de Luca-Fraga & Pimenta, 2001; Güngör & others, 2003). Newer brands of these restorative materials with enhanced flow characteristics for fissure sealing have been marketed recently. Therefore, a double-blind clinical study was carried out to evaluate the retention, marginal integrity and caries-preventing effect of a polyacid-modified resin composite based fissure sealant, Dyract Seal compared with those of a fluoride fissure sealant, Delton FS+.

METHODS AND MATERIALS

Sample Selection

The sample consisted of healthy schoolchildren between 7 and 10 years of age who were referred to the Department of Pediatric Dentistry Clinics for routine dental examination. The patients were residents of areas without flouridated water. Fifty-three patients (26 males, 27 females) were recruited for inclusion in this clinical study based on fulfilling the following criteria:

a. Patients had their permanent first molars fully erupted.
b. At least two first molars required invasive technique for sealant placement (De Craene, Martens & Dermaut, 1988; Ripa & Wolff, 1992).
c. The permanent molars were free of occlusal-dentin and approximal caries as observed on the bite-wing radiographs.
d. The patient had no bruxism, malocclusion or known allergy against dental resins or latex.
e. Parental informed consent was obtained.

Sealant Placement

Two types of fissure sealants were used in this study: a) Dyract Seal (Dentsply DeTrey, Konstanz, Germany), a polyacid-modified resin composite applied in combination with Total Seal Technique; b) Delton FS+ (Dentsply International York, PA, USA), a fluoridated BisGMA-based sealant used as a control. Table 1 shows the composition of materials used in the study.

The teeth to be sealed were cleaned with a bristle brush rotating on a low-speed handpiece with irrigation. The occlusal surfaces were prepared using the invasive technique described by De Craene and others (1989) and García-Godoy and de Araujo (1994). Diamond burs in high-speed instruments were used for this purpose (Diatech Dental Instruments, 858/012-8 ML, Switzerland). The rationale for selecting this bur was the bur taper, which provides a very fine tip that enables the clinician to avoid unnecessary enlargement of the fissures. Care was taken not to penetrate the dentin during this procedure. In the case of caries or exposed dentin, those teeth were excluded from the study.

One operator applied the sealants. During each appointment, patients received all sealants required for their teeth. The sealants were applied randomly to the right/left side of the maxilla/mandibula using a table of random numbers. The teeth were isolated with cotton rolls and saliva ejectors were used throughout the procedure. The sealant application protocol is detailed as follows:

Dyract Seal

Following air drying of the tooth, NRC (Non-Rinse Conditioner, Dentsply DeTrey, Konstanz, Germany) was applied to the occlusal surface and left undisturbed for 20 seconds. The material was not rinsed; however, the excess was removed by blowing gently with an air syringe. Prime & Bond NT (Dentsply DeTrey, Konstanz, Germany) was applied to the fissures with a

Table 1: *The Composition of Materials Used in the Study*

Material	Composition
NRC	Itaconic and maleic acid, water
Prime & Bond NT	Di- and trimethacrylate resins, PENTA, UDMA resins, photoinitiators, Cetylamine hydrofluoride, acetone
Dyract Seal	Aminopenta, macromonomer, DGDMA, aerosil, inhibitor, initiators, strontium-aluminum-fluorosilicate glass
Delton EZ Etch	34% phosphoric acid gel
Delton FS+	Low viscosity monomers, TEGDMA, BisGMA, sodium fluoride, initiators, stabilizers, silicon dioxide, barium alumio fluroboro silicate glass

disposable brush for 20 seconds. After the solvent was removed by blowing gently for five seconds, Dyract Seal was placed immediately and light cured for 40 seconds.

Delton FS+

The occlusal surface of the tooth was treated with Delton EZ Etch (Dentsply International, York, PA, USA) for 30 seconds. The etching agent was rinsed for 15 seconds and thoroughly air-dried. Delton FS+ was applied and light cured for 40 seconds. On maxillary permanent molars, an extra 40-second polymerization was done for the palatal surfaces.

The curing unit used in this study, Hilux 200 Curing Light (Benlioglu Dental Inc, Ankara, Turkey), had a light output of 500 mW/cm^2. Curing efficiency was assessed before use with each patient. During the polymerization of fissure sealant materials, the tip of the light surface was kept a minimum distance from the surface without touching it. The oxygen-inhibited surface layer formed after light curing was removed with cotton pellets. The sealed area was checked with an explorer for complete coverage and retention. If complete re-sealing or additional sealant material was required, it was accomplished at that session. The occlusion was checked with articulating paper for premature occlusal contacts and, if necessary, corrected with a finishing bur.

The patients were scheduled for evaluation visits at 3, 6, 12 and 24 months. Before leaving, the patients were given diet advice and also instructed on brushing with fluoridated toothpaste.

Evaluation

Since the study had a double-blind design, both the patients and evaluator were blind to the materials used. The evaluator was different from the operator and the materials were sufficiently similar in appearance to allow the evaluator to be blinded. The sealants were evaluated in terms of retention (1=present, 2=partially present or 3=lost) and the presence of caries (1=present or 2=absent). The marginal integrity of sealants was also evaluated using the USHPS system (Koch & others, 1997): Alpha=excellent margin with no evidence of crevice; Bravo=an acceptable margin with a small crevice detected and Charlie=an unacceptable margin with larger crevice present. After each evaluation visit, only professional tooth cleansing procedures were performed by the operator using slurry of pumice and a rubber cup rotating on a low-speed handpiece.

Chi-square tests were used to evaluate whether there were statistically significant differences between the fissure sealant materials. The α value was set at 0.05.

RESULTS

A total of 192 teeth (94 mandibular and 98 maxillary) were sealed with either Dyract Seal (n=96) or Delton FS+ (n=96) at baseline. The number of teeth available for evaluation at postoperative 3, 6, 12 and 24 months were 192, 174, 158 and 140, respectively. Tables 2 to 4 show the results obtained throughout the study period with respect to each evaluation parameter.

Dyract Seal showed complete retention on teeth with rates of 100.0%, 98.9%, 91.1% and 80.0% at 3-, 6-, 12- and 24-month evaluations, respectively. The corresponding Delton FS+ rates were 100.0%, 96.6%, 86.1% and 71.4% for the same evaluations, respectively. The differences for each evaluation period were statistically insignificant ($p>0.05$). The teeth sealed with Dyract Seal were caries-free at 3, 6, 12 and 24 months, with the rates decreasing as 100.0%, 100.0%, 93.7% and 85.7%, respectively. The Delton FS+ figures for the same evaluation periods were 100.0%, 97.7%, 88.6% and 82.9%, respectively. There were no statistically significant differences between both sealant materials with respect to caries preventing ability for any evaluation period ($p>0.05$). Regarding marginal integrity scores, the differences between Dyract Seal and Delton FS+ were found to be statistically significant except for the 24-month evaluation ($p<0.05$). At 3-, 6- and 12-month evaluations, Dyract Seal had marginal integrity rates of 34.4%, 59.8% and 65.9%, respectively. However, the c rates for the same evaluation periods were 100.0%, 95.4% and 81.0%, respectively, for Delton FS+.

DISCUSSION

In this study, the clinical efficacy of a polyacid-modified resin composite-based fissure sealant was evaluated on permanent first molars that were prepared invasively prior to sealant application. The selection of a non-invasive or invasive technique has been a matter of debate in the dental literature (Meiers & Jensen, 1984). However, in a study by Primosch and Barr (2001), where sealant use and placement techniques were surveyed among pediatric dentists, it was reported that 87% of the respondents had stated that they were "always or sometimes" using surface preparation in sealant application. Higher retention rates for fissure sealants have been reported where mechanical preparation of fissures had been carried out (Shapira & Eidelman, 1986; De Craene & others, 1989; Gray, 1999; Ganss, Klimek & Gleim, 1999; Lygidakis & Oulis, 1999). *In vitro* studies have demonstrated a decline in microleakage risk when fissure sealants were applied with invasive technique (Geiger, Gulayev & Weiss, 2000; Salama & Al-Hammad, 2002; Güngör & others, 2002).

The use of invasive technique in pit-and-fissure sealing has been suggested as a prophylactic treatment for deep, narrow fissures of occlusal surfaces that are discolored and suspected of being carious (De Craene & others, 1988). The most important advantage of the invasive technique is that it can be used as a diagnostic tool for the suspected fissures. It allows the clinician to

clean the fissure entrance and inspect and determine the extent of the carious lesion, if any, toward the dentinoenamel junction (De Craene & others, 1988). In this study, the teeth where exposed dentin or caries below the dentinoenamel junction was observed during mechanical preparation were excluded from the study.

The retention rate becomes a major point of concern when a study tests the clinical performance of a fissure sealant material (Lygidakis & Oulis, 1999; de Luca-Fraga & Pimenta, 2001; Autio-Gold, 2002). Since the retention rate is often associated with success (Ripa, 1985; Ripa, 1993; Wendt, Koch & Birkhed, 2001), it has been one of the frequently evaluated parameters (Koch & others, 1997; Ganss & others, 1999; Pereira & others, 2000). At the end of the second year, complete retention rates of Dyract Seal and Delton FS+ were 80.0% and 71.4%, respectively. In a clinical study by Ganss and others (1999), Helioseal F and Fissurit F were reported to have 53.4% and 44.6% retention rates after one year, respectively. After four-year follow-up, Lygidakis and Oulis (1999) reported a decline in complete retention rate (77%) for Fluroshield (Caulk/Dentsply, Milford, DE, USA) when compared to Delton (89%) (Dentsply International, York, PA, USA). Both studies have used the invasive technique prior to applying fissure sealants. After one year clinical testing, Koch and others (1997) reported a 90.3% complete retention rate for Helioseal F (Vivadent, Schaan, Liecthenstein) which was applied to mandibular permanent molars following fissure cleansing with Prophy-Jet 25 (DeTrey, Dentsply, USA). de Luca-Fraga and Pimenta (2001) used Dyract as a fissure sealant on permanent molars and reported a complete retention rate of 95.9% after one year. However, a study by Pereira and others (2000) presented 5% complete retention for Variglass VLC (Caulk/Dentsply), a polyacid-modified resin, after four years of clinical service. The criteria for patient/tooth selection, the isolation technique used, the operator technique, the choice of materials and the clinical performance evaluation methods used have possibly been associated with the variation in results found among these studies.

Although there were no statistically significant differences for complete retention rates between materials, Dyract Seal rated better than Delton FS+ throughout the study. Prior to applying Dyract Seal, NRC (Non-Rinse Conditioner) and the bonding agent, Prime & Bond NT, were used. The manufacturer defined this application procedure as Total Seal Technique. The most important advantage of this technique is associated with the use of NRC. There is a possible risk of saliva contamination of the acid-etched surface, which is often

Table 2: *Distribution of Retention Rates in the Study (p>0.05 for all evaluation periods)*

	Dyract Seal				Delton FS+			
Score	3rd Month	6th Month	12th Month	24th Month	3rd Month	6th Month	12th Month	24th Month
1	96 (100.0%)	86 (98.9%)	72 (91.1%)	56 (80.0%)	96 (100.0%)	84 (96.6%)	68 (86.1%)	50 (71.4%)
2	-	1 (1.1%)	7 (8.9%)	11 (15.7%)	-	3 (3.4%)	11 (13.9%)	11 (15.7%)
3	-	-	-	3 (4.3%)	-	-	-	9 (12.9%)
Total	96	87	79	70	96	87	79	70

p>*0.05 for all evaluation periods*

Table 3: *Distribution of Caries Scores in the Study (p>0.05 for all evaluation periods)*

	Dyract Seal				Delton FS+			
Score	3rd Month	6th Month	12th Month	24th Month	3rd Month	6th Month	12th Month	24th Month
1	96 (100.0%)	87 (100.0%)	74 (93.7%)	60 (85.7%)	96 (100.0%)	85 (97.7%)	70 (88.6%)	58 (82.9%)
2	-	-	5 (6.3%)	10 (14.3%)	-	2 (2.3%)	9 (11.4%)	12 (17.1%)
Total	96	87	79	70	96	87	79	70

p>*0.05 for all evaluation periods*

Table 4: *Distribution of Marginal Integrity Scores in the Study*

	Dyract Seal				Delton FS+			
Score	3rd Month	6th Month	12th Month	24th Month	3rd Month	6th Month	12th Month	24th Month
A	33 (34.4%)	35 (59.8%)	52 (65.9%)	57 (81.4%)	96 (100.0%)	83 (95.4%)	64 (81.0%)	49 (70.0%)
B	63 (65.6%)	52 (40.2%)	25 (31.6%)	7 (10.0%)	-	4 (4.6%)	14 (17.7%)	12 (17.1%)
C	-	-	2 (2.5%)	6 (8.6%)	-	-	1 (1.3%)	9 (12.9%)
Total	96	87	79	70	96	87	79	70

Superscripts a,b,c represent statistically significant difference for evaluation months with same letters (p<0.05).

encountered by clinicians during the change of cotton rolls following rinsing of the acid etchant. It has been reported that salivary contamination of etched enamel for one second or longer resulted in the formation of surface coatings that could not be removed by a water wash (Silverstone, Hicks & Featherstone, 1985). When overlooked, this contamination lowers the cost-effectiveness of fissure sealing as a consequence of early loss of the material.

Prime & Bond NT is another factor that might have contributed to better retention of Dyract Seal. Due to its components (di- and trimethacrylate resins, PENTA) and hydrophilic characteristics (originating from acetone), it could be anticipated that Prime & Bond NT promoted penetration of the material into the microporosities created (Güngör & others, 2003). Clinical and laboratory studies have reported that the retention rate, microleakage, bond strength and the vertical penetration of fissure sealants were significantly improved when a bonding agent was used prior to their application (Feigal, Hitt & Splieth, 1993; Symons, Chu & Meyers, 1996; Tulunoglu & others, 1999; Perez-Lajarin & others, 2003; Güngör & others, 2003). However, in a clinical study of sealants with and without bonding agent, Boksman and others (1993) have reported no benefit regarding the use of a bonding agent. The authors of this study are in agreement with Simonsen (2002), who stated in a recent literature review that while not all studies agree, it seems appropriate to speculate that modern bonding agents could improve sealant retention.

Another factor associated with Dyract Seal retention rates may be the hygroscopic expansion characteristics of this material. Dyract Seal is a polyacid-modified resin composite with two curing reactions that occur following application: the quick photoinitiated polymerization and the subsequent slow acid-base reaction. Since acid-base reaction cannot occur instantly, as the material does not contain water, the carboxylic groups of Dyract Seal remain inactive at this stage. Only after water uptake, which lasts several weeks or months, carboxylic salts are formed that are simultaneously accompanied by the release of fluoride salts (Hse & others, 1999). PMRC materials have been reported to expand hygroscopically up to 3% of their mass (Hickel & others, 1998). Hence, hygroscopic expansion of the material within fissures that occurred during acid-base reaction might have improved the mechanical retention of Dyract Seal (Eliades, Kakaboura & Palaghias, 1998; Çehreli & Altay, 2000).

After two years, teeth sealed with Dyract Seal and Delton FS+ were found to be caries-free, with rates of 85.7% and 82.9%, respectively, indicating a statistically insignificant difference. Lygidakis and Oulis (1999) have reported that 90% of the permanent molars sealed with Fluroshield remained caries-free at the end of the fourth year. Çehreli and Altay (2000), after a three-year clinical evaluation, reported a caries-free rate of 96.6% for minimally-invasive cavities on permanent first molars restored with Dyract. In a one-year clinical study by de Luca-Fraga and Pimenta (2001), the number of caries-free mandibular permanent first molars sealed with Dyract was 194 out of 196.

In this study, the observed high caries rate in both sealant groups could be attributed to the relatively low socio-economic and cultural status of the patients. At each evaluation visit, a prophylaxis without a fluoride treatment was carried out. The rationale for this was based on the *in vitro* study by Kula and others (1992), who reported surface deterioration and weight loss of filled sealants when treated with topical acidulated and neutral fluoride gels. Since both sealant materials used in this study were filled to some degree, this procedure was chosen.

In this study, Dyract Seal had lower marginal integrity scores when compared to Delton FS+ at 3-, 6- and 12-month evaluations for which the differences were statistically significant. This result might be explained by the observations of Fuks, Eidelman and Lewinstein (2002), who reported lower shear bond strength of Dyract Seal when used with NRC + Prime & Bond NT. In a laboratory study, they compared the shear bond strengths of Dyract Seal and Helioseal placed with either NRC or a conventional acid etch-rinse technique. Dyract Seal was used with NRC + Prime & Bond NT, which resulted in the second lowest mean bond strength of the study groups. The authors have concluded that using non-rinse conditioner with Dyract Seal led to considerably lower shear bond strength values than Dyract Seal and Helioseal with phosphoric acid etching and rinsing.

One of the interesting observations of this study was the gradual improvement of marginal integrity of Dyract Seal in time. At the end of the second year, Dyract Seal showed comparable, even better marginal integrity rates compared to Delton FS+. The difference was statistically insignificant. The explanation for this condition lies in the low wear resistance of PMRC materials—compared to resin composites—which might have helped the material itself wear away easily from the surface to create better marginal integrity over an extended period of time (Çehreli & Altay, 2000).

CONCLUSIONS

Under the conditions of this two-year clinical study, it can be concluded that sealing permanent teeth with Dyract Seal and Delton FS+, using invasive technique, was found effective in terms of retention and caries prevention. However, the lower marginal integrity scores of Dyract Seal that were found to improve after one year remain a topic of interest which has to be explored further clinically.

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Six-year Clinical Evaluation of Bonded and Pin-retained Complex Amalgam Restorations

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Clinical Relevance

Bonding with a filled, 4-META-based bonding resin appears to be a satisfactory method for retaining large amalgam restorations replacing cusps.

SUMMARY

This clinical study compared the performance of complex amalgam restorations retained with self-threading pins or bonded with a filled, 4-META-based resin. Sixty amalgam restorations (28 pin-retained and 32 bonded), each replacing at least one cusp, were placed. Self-threading stainless steel pins (Coltene-Whaledent) were used in the pin-retained group. A filled, 4-META-based bonding resin (Amalgambond Plus with HPA powder) was used in the bonded group. For both groups, any retention form remaining after removal of an old restoration was left in place but not enhanced. At six years, 11 restorations had failed; eight of which were pin-retained and three bonded. Using Fisher's exact test to compare the groups at six years, there was no significant difference in failure rate, marginal adaptation, marginal discoloration, secondary caries, tooth sensitivity or tooth vitality. At six years, there was no difference in the performance of pin-retained amalgam restorations and bonded amalgam restorations.

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INTRODUCTION

Threaded pins (Markley, 1958; Going, 1966), boxes (Birtcil & Vinton, 1976), amalgapins (Shavell, 1980) and slots (Outhwaite, Garman & Pashley, 1979) have been shown to provide retention and resistance for complex amalgam restorations replacing cusps (Robbins, Burgess & Summitt, 1989). These mechanical resistance/retention features have served well to keep restorations in place, but each comes with associated risks (Robbins & others, 1989; Webb, Straka & Phillips, 1989). If these invasive means of resistance/retention could be replaced by a non-invasive method, these risks could be avoided (Gwinnett & others, 1994).

Parkell introduced a 4-META-based amalgam bonding system in 1989, the first such system marketed in the United States. Other amalgam bonding systems have since been developed. Some manufacturers have altered existing products to allow their use for bonding amalgam. Many *in vitro* studies have evaluated the adhesive and cavity-sealing capabilities of amalgam bonding products. There have also been clinical studies testing the performance of some of these materials.

In amalgam bonding, the mechanism for attachment of the bonding resin to tooth structure is identical to the mechanism that resin bonding systems use to attach resin composite to dentin and enamel. Attachment of the bonding resin to amalgam, however, is quite different from attachment of the bonding resin to resin composite. The amalgam-to-resin attachment is entirely mechanical. Unset amalgam is condensed into the bonding resin covering the cavity walls prior to polymerization of the resin. This incorporates "fingers" of resin into the amalgam mass at the interface (Nakabayashi, Watanabe & Gendusa, 1992).

The mechanical attachment of amalgam to the bonding resin is enhanced by the incorporation of filler particles, either organic or inorganic, into the resin (Imbery, Burgess & Batzer, 1995; Bagley, Wakefield & Robbins, 1994; Diefenderfer & Reinhardt, 1997; Miller & others, 1998). A probable reason for this improvement in attachment is that the filled bonding resin is more viscous. During condensation of the amalgam, the more viscous bonding resin penetrates better into the amalgam, thus providing increased mechanical retention.

In vitro studies have demonstrated that the resistance to a shearing load created by amalgam bonding can be equal to or greater than resistance provided by mechanical features such as pins (Imbery & others, 1995; Burgess, Alvarez & Summitt, 1997; Rosen, Hermesch & Summitt, 1998). Other studies have revealed that Amalgambond Plus (Parkell, Farmingdale, NY, USA), with its polymethyl methacrylate filler, provides one of the strongest bonds of amalgam to tooth structure (Imbery & others, 1995; Diefenderfer & Reinhardt, 1997; Miller & others, 1998; Rosen & others, 1998; Vargas, Denehy & Ratananakin, 1994; Ramos & Perdigão, 1997).

Several clinical studies of bonded amalgam restorations have been reported. Mahler and colleagues evaluated teeth with bonded and non-bonded Class II amalgam restorations and reported no difference in tooth sensitivity two weeks post-insertion or in marginal fracture after one (Mahler & others, 1996) or three years (Mahler & Engle, 2000). Belcher and Stewart (1997) compared the clinical success of complex amalgam restorations retained with pins against Amalgambond Plus with no filler powder or with Amalgambond Plus with filler powder. At two years, all restorations in all three groups were retained with minimal sensitivity, good marginal adaptation and no recurrent caries. Staninec and others (1997) reported two-year success of bonded amalgam restorations in primary teeth. An *in vivo* study by Smales and Wetherell (2000) evaluated 366 bonded amalgam restorations using five different bonding materials. Cuspal coverage was accomplished in 178 of the 366 restorations. They reported a 98.6% success rate at up to five years.

This clinical study compared failure rates, marginal adaptation, marginal discoloration, secondary caries rates, sensitivity and tooth vitality of bonded and pin-retained complex amalgam restorations. This paper reports the results after six years. The five-year results were published previously (Summitt & others, 2001).

METHODS AND MATERIALS

Patients selected for the study had a posterior tooth or teeth requiring restoration of at least one proximal surface and one or more cusps. The teeth to be restored had at least one proximal contact and occluded with natural or restored teeth. In the study, 60 teeth (57 molars and 3 premolars) were restored with amalgam, 28 using pin retention and 32 using the amalgam bonding system. For each mouth requiring more than one restoration, a coin toss determined which tooth or teeth received bonded restoration(s) and which received pin-retained restoration(s). If the patient was to receive only one restoration, the coin toss was also used to determine which type of restoration would be done. The next patient with only one restoration automatically received the other type of restoration.

Patients read and signed the consent form approved by the Institutional Review Board (IRB) of the University of Texas Health Science Center at San Antonio. Patients excluded from participation in the study were those who could not tolerate the procedures, had compromised immune systems or compromised salivary flow or would not be available for long-term recall.

Five operators, all experienced clinicians, placed the restorations. The operators were calibrated to guidelines concerning resistance features and use of the bonding system. Pulpal vitality was confirmed preoperatively via electric pulp testing and thermal testing. A preoperative radiograph was made to assure that there was no radiographic evidence of pulpal pathosis. Rubber dam isolation was used during tooth preparation, amalgam placement and initial carving of all restorations.

For both groups, any retention form remaining after removal of an old restoration was left intact but was not enhanced. For all restorations, enough occlusal tooth structure was missing or removed to ensure at least a

2-mm thickness of amalgam in all occlusal areas.

The guideline for pin placement stated that one vertical pin was used for each missing cusp, with a maximum of four vertical pins. Horizontal pins were placed at the operator's discretion. TMS (Thread-Mate System, Coltene-Whaledent, Mahwah, NJ, USA) Minim (0.024" diameter) vertical pins and Minikin (0.019" diameter) horizontal pins were used. Pin channels were prepared with depth-limiting TMS pin channel drills to a depth of 2 mm for Minim pins and 1.5 mm for Minikin pins. Two coats of Copalite varnish (Cooley & Cooley, Ltd, Houston, TX, USA) were applied after pin channel preparation and prior to pin placement. A stainless steel matrix was applied after pin placement.

No mechanical retention form was added for the resin-bonded restoration group. The Amalgambond Plus bonding system (Parkell, Farmingdale, NY, USA) provided the only enhancement of retention and, in some cases, the primary means of retention. A stainless steel matrix was placed prior to using any portion of the bonding system. The instructions for Amalgambond Plus state that it may be used with or without incorporating a poly methyl-methacrylate filler powder called *High Performance Additive (HPA powder)*. The HPA powder was incorporated into all the bonding resin in this study according to the manufacturer's instructions for *extra retention*. *The Dentin Activator* (10% citric acid and 3% ferric chloride) was applied in accordance with the manufacturer's instructions (approximately 30 seconds to enamel and 10 seconds to dentin). The prepared tooth surface was rinsed with air/water spray and briefly dried with air. *The Adhesive Agent* (containing HEMA) was applied to all pre-

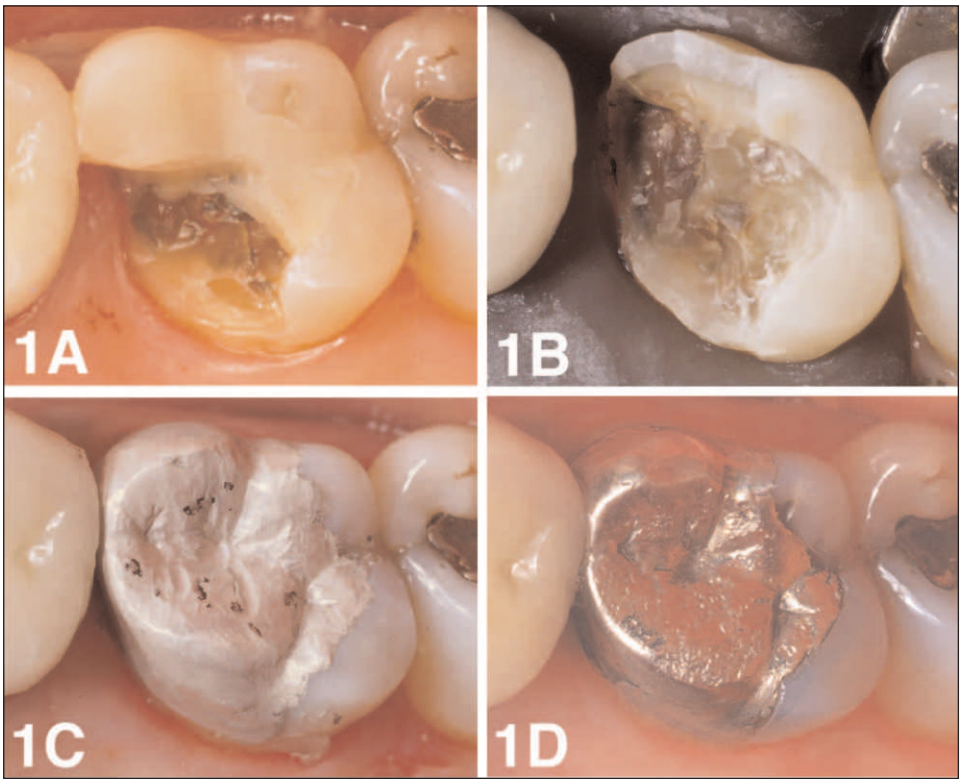

Figure 1. *A bonded restoration in tooth #14: A) pre-operative view; B) preparation, showing gingivally deep extension in mesial aspect; C) restoration immediately after completion; D) restoration after six years.*

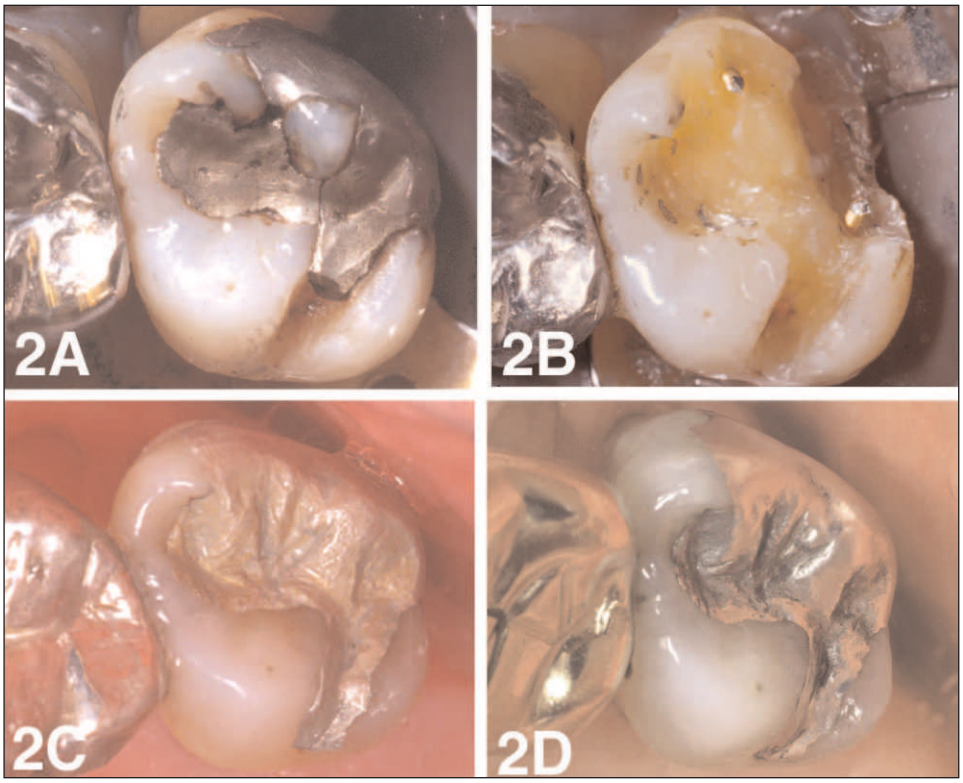

Figure 2. *A pin-retained restoration in tooth #15: A) pre-operative view; B) preparation after pin placement; C at baseline evaluation; D) restoration after six years.*

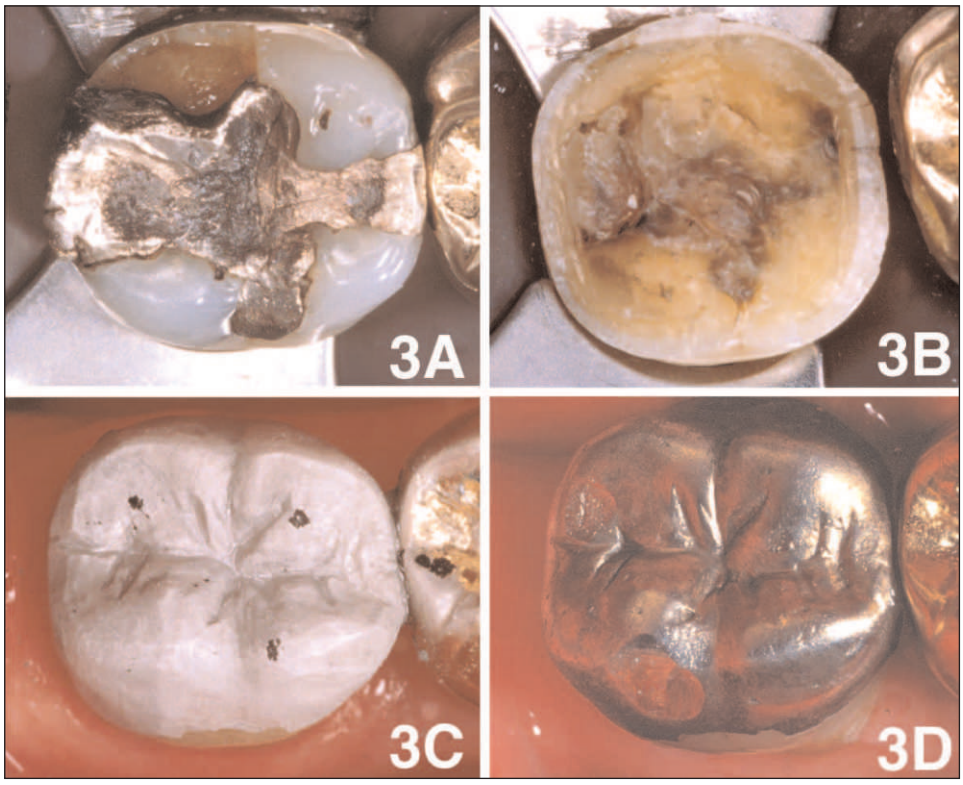

Figure 3. *A bonded restoration in tooth #31 that had no mechanical resistance/retention features: A) pre-operative view; B) preparation; C) restoration immediately after completion with occlusal contacts marked and all excursive contacts removed; D) restoration after six years.*

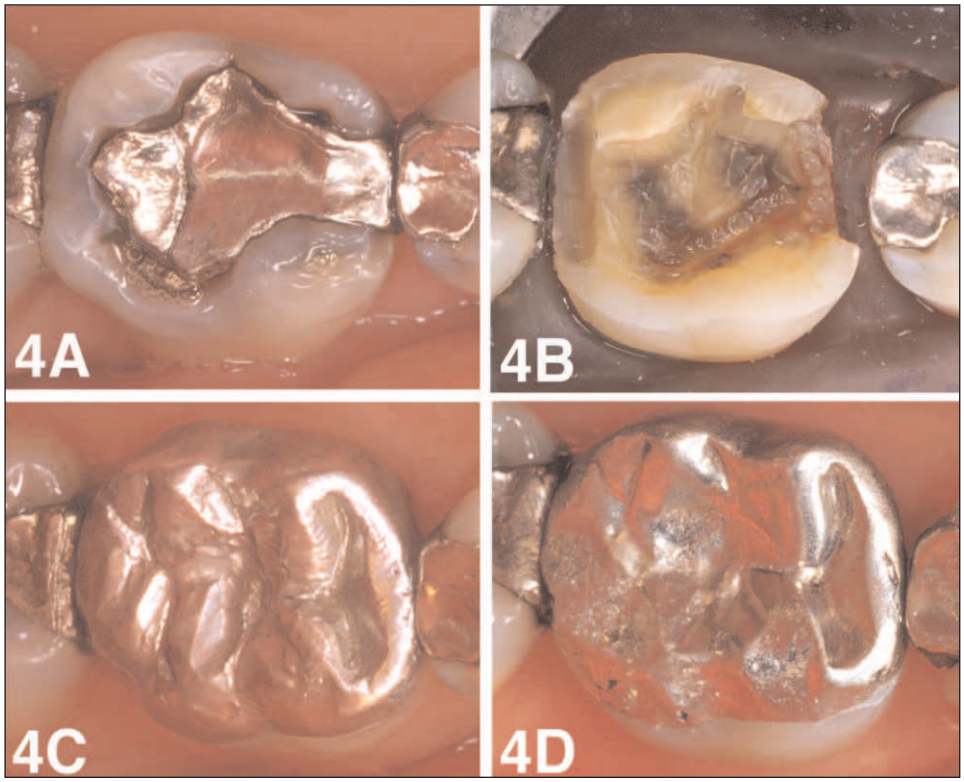

Figure 4. *A bonded restoration in tooth #30: A) pre-operative view; B) preparation; C) at baseline evaluation; D) restoration after six years.*

pared surfaces, gently thinned with an air stream and left undisturbed for at least 30 seconds. Components of the resin adhesive (3 drops of *base*, 1 scoop of *HPA powder* and 1 drop of *catalyst*) were mixed together while a spherical amalgam (Tytin, Kerr Corp, Glendora, CA, USA) was being triturated. All walls of the preparation were coated with the resin adhesive using a Kerr Applicator (Kerr Corp, Glendora, CA, USA) to provide a thin coat of the material.

Tytin amalgam was hand condensed. For pin-retained restorations, amalgam was inserted and spread over preparation floors so that increments no more than 1 mm in vertical thickness were condensed. Both vertical and horizontal condensation strokes were used. For restorations employing bonding resin, amalgam was inserted and condensed against all walls within one minute from the start of the mix of Amalgambond Plus. First priority was given to condensing against all walls of the preparation to assure that the amalgam was condensed into the bonding resin before it had polymerized. After all walls were covered with amalgam, additional increments of amalgam were inserted and condensed using the same method as described for the pin-retained group. Amalgam was condensed to a vertical height approximately 1 mm in excess of the predicted occlusal extent of the restoration.

Burnishers and carvers were used to shape the occlusal surface of each restoration prior to matrix removal. The matrix was then removed and the restoration carved to proper anatomical form. After rubber dam removal, the occlusion was adjusted to provide contact in maximum intercuspation (centric occlusion) and to eliminate contact in eccentric mandibular excursions. The amalgam surface was smoothed using

wet flour pumice in a rubber cup in a low-speed handpiece running at low speed; burnishers were also used. Restorations were not polished. A total of 60 teeth were restored in the mouths of 28 patients.

Photographs (35-mm slides) of the preparation and the restored tooth were taken preoperatively immediately after completion of the restoration. Photographs were also taken of the restored tooth at each recall appointment. Figures 1 through 4 show representative photographs of teeth taken pre-operatively, tooth preparations, restorations immediately after placement and the same restorations at six years.

Evaluators were calibrated in the use of an explorer to detect marginal discrepancies and in determining tooth sensitivity, tooth vitality, marginal discoloration and secondary caries. Patients were recalled for a baseline evaluation approximately one week post-operatively. Patients were also recalled for evaluation at six months, one year, two years, three years, four years, five years and six years. At each recall evaluation, tooth vitality was confirmed thermally and with an electric pulp tester. Tooth sensitivity was assessed thermally. In addition, marginal integrity, marginal discoloration and secondary caries were evaluated using modified Cvar/Ryge criteria (Cvar & Ryge, 1971) as indicated in Table 1.

Table 1: *Modified Cvar/Ryge Criteria Used to Evaluate Restorations*

Marginal Adaptation	Alpha (α)	Margins closed; explorer does not catch
	Bravo (β)	Crevice exists; explorer penetrates at interface and catches when moved from tooth surface to restoration surface and restoration to tooth; dentin not exposed
	Charlie (C)	Crevice evident, with dentin exposed
Marginal Discoloration	Alpha (α)	No discoloration anywhere along the margin
	Bravo (β)	Discoloration is present but has not penetrated in a pulpal direction along the margin
	Charlie (C)	Discoloration has penetrated in a pulpal direction
Secondary Caries	Alpha (α)	No caries present
	Charlie (C)	Caries present
Tooth Sensitivity	Alpha (α)	Less than or equal to control tooth
	Bravo (β)	More than control tooth
Tooth Vitality	Alpha (α)	Tooth Vital
	Charlie (C)	Tooth non-vital; endodontic therapy required

Table 2: *Ratings for Pin-Retained Restorations by Time of Service*

Category	Baseline	6 Months	1 Year	2 Years	3 Years	4 Years	5 Years	6 Years
Marginal Adaptation	26 α	25 α	20 α 3 β 1 C	17 α 5 β 1 C	12 α 9 β 2 C	10 α 10 β 3 C	6 α 10 β 3 C	4 α 7 β 4 C
Marginal Discoloration	26 α	25 α	23 α	22 α	21 α	17 α 3 β	11 α 5 β	9 α 2 β
Secondary Caries	26 α	25 α	23 α	22 α	21 α	20 α	16 α 2 C	11 α 3 C
Thermal Sensitivity	11 α 15 β	7 α 18 β	4 α 19 β	13 α 9 β	13 α 8 β	11 α 9 β	5 α 11 β	4 α 7 β
Tooth Vitality	26 α	25 α	23 α 1 C	22 α 2 C	21 α 2 C	20 α 2 C	16 α 2 C	12 α 2 C

Table 3: *Ratings for Bonded Restorations by Time of Service*

Category	Baseline	6 Months	1 Year	2 Years	3 Years	4 Years	5 Years	6 Years
Marginal Adaptation	29 α	28 α	27 α	23 α 3 β	20 α 6 β	19 α 6 β	15 α 6 β 1 C	5 α 9 β 1 C
Marginal Discoloration	29 α	28 α	27 α	26 α	26 α	24 α 1 β	20 α 1 β	13 α 2 β
Secondary Caries	29 α	28 α	27 α	26 α	26 α	25 α 1 C	21 α 1 C	15 α 2 C
Thermal Sensitivity	18 α 11 β	18 α 10 β	11 α 16 β	11 α 15 β	15 α 11 β	18 β 7 β	11 α 10 β	5 α 9 β
Tooth Vitality	29 α	28 α	27 α	26 α	26 α	25 α	21 α	14 α

Tooth sensitivity was assessed by using a cotton pellet, or the tip of a cotton-tipped applicator saturated with Frigi-Dent (Ellman International, Inc, Hewlett, NY, USA). The cold stimulus was first placed on the facial surface of a non-restored, non-carious tooth (control), then on the facial surface of each restored tooth. The patient rated the sensation in each restored tooth the same as, more than or less than the control tooth.

RESULTS

Tables 2 and 3 show the results. Of the total of 28 patients with 60 restorations, two bonded restorations were determined not to have met selection criteria for the study and were excluded from consideration. Two patients with three restorations (two pin-retained and one bonded) did not return for baseline evaluation and were therefore eliminated from the study. One patient with two restorations (one pin-retained and one bonded) was lost from the study after baseline and prior to the six-month evaluation. One patient with one bonded and one pin-retained restoration was lost to the study after the six-month evaluation due to a stroke. Another patient with a bonded restoration did not return after the one-year recall. Three patients with three bonded restorations and two pin-retained restorations were unavailable for the five- and six-year recalls because they had moved away; at four years, all five of those restorations were performing satisfactorily. Of the remaining 46 restorations (23 bonded and 23 pin-retained), six (five pin-retained and one bonded) had failed prior to the five-year recall. At the six-year recall, 27 of the original 60 restorations were available for evaluation. Twelve were pin-retained and 15 were bonded Nine restorations had failed prior to the six-year recall and had been eliminated from further evaluation. Twenty-five of the 27 restorations evaluated at six years were performing satisfactorily (11 pin-retained and 14 bonded). The restorations were classified as having failed when they had to be replaced, required major repair or when the tooth needed endodontic treatment or extraction. Failures were as follows:

Required Endodontic Therapy—Two molars with pin-retained restorations required endodontic therapy, one after six months but prior to the one-year evaluation and one at year two. Both were successfully restored after endodontic therapy.

Significant Tooth Fracture Adjacent to Restoration—Three molars restored with pin-retained restorations suffered significant fracture, one each at years one, three and four. These fractured teeth were restorable. One molar restored with a bonded restoration suffered significant fracture, including root fracture, at year five and was extracted.

Secondary Caries—One molar restored with a bonded restoration had secondary caries (adjacent to the restoration) at year four and one at year six. Three molars restored with pin-retained restorations had secondary caries (adjacent to the restorations), two at year five and one at year six. All carious teeth were restored.

Fisher's exact test was used to compare the failure rate of the two groups, bonded and pin-retained. There was no significant difference in failure rate (p=0.05) at six years. In addition, there was no significant difference between groups in any category. P values were as follows: marginal adaptation (p=0.647), marginal discoloration (p=0.466), secondary caries (p=0.773), sensitivity (p=1.000), tooth vitality (p=0.648) and failure rate (p=0.109). During the six years of this study, the only time where there was a significant difference in tooth sensitivity was at six months (p=0.013).

Bonded restorations were performing as well as pin-retained restorations in all categories at six years.

DISCUSSION

Published results of clinical studies have shown bonded amalgam restorations to function well (Mahler & others, 1996; Mahler & Engle, 2000; Belcher & Stewart, 1997; Staninec & others, 1997; Smales & Wetherell, 2000; Kennington & others, 1998). In these studies, bonded amalgam restorations were compared to mechanically retained amalgam restorations. The bonded restorations were reported to be performing as well as the mechanically retained restorations. In this study, restorations involving replacement of one or more cusps with amalgam demonstrated similar performance. These large restorations were exposed to more stress during function than simple Class I or Class II amalgam restorations. Predictably, there were more failed restorations in this study than in studies involving smaller restorations.

Several clinical investigations have demonstrated no difference in sensitivity between teeth restored with or without bonding (Mahler & others, 1996; Mahler & Engle, 2000; Belcher & Stewart, 1997; Smales & Wetherell, 2000; Kennington & others, 1998; Browning, Johnson & Gregory, 2000). Other studies, however, have shown reduced thermal sensitivity when the amalgam restorations were bonded (Davis & Overton, 2000; Hadi, Rosenstiel & Rashid, 1998). One study (Davis & Overton, 2000) involved teeth that had symptoms of incomplete tooth fracture prior to restoration. The investigators found sensitivity to a cold temperature stimulus (skin refrigerant) reduced in the teeth with bonded restorations at three and 12 months after placement, compared to baseline. In contrast, teeth with restorations that were based but not bonded demonstrated no reduction in thermal sensitivity. Another study (Hadi & others, 1998), comparing bonded amalgam restorations

(bonded with Amalgambond Plus) with those where a cavity varnish (Copaliner, Harry J Bosworth Co) was used, surveyed patients the day after the restorations were placed and found significantly less sensitivity in the bonded group. The current study reported no difference in tooth sensitivity between bonded and non-bonded restorations at any point except at six months. The fact that there was no difference at baseline compares with the results of the Davis and Overton (2000) study. Possibly, the lack of a difference at baseline could be due to recent mechanical trauma during tooth preparation that opened dentinal tubules, predisposing teeth with bonded and non-bonded restorations to minor post-operative thermal sensitivity. At six months in this study, and at three and 12 months in the Davis-Overton study, teeth with bonded restorations exhibited less sensitivity than those with non-bonded restorations. This difference was possibly due to the improved seal of tubules provided by the resin adhesive and elapsed time since restoration.

In most studies, marginal discoloration is not a criterion for the evaluation of amalgam restorations. It was included in this study because of the bonding resin used and the ability, in some areas, to see into the bonding resin. No attempt was made to discriminate between staining at the amalgam-resin interface and the amalgam-enamel interface.

It should be noted that several of the bonded restorations in this study had little or no mechanical retention form (Figures 1 and 3), yet none of them had dislodged.

It is interesting that, even though the bond strength provided by amalgam bonding agents for amalgam is lower than the bond strength provided by bonding agents for resin composite, it seems to be adequate even for very large restorations. This is, perhaps, due to the fact that amalgam does not exert significant stress on the bonding mechanism as it sets, while resin composite, as a result of polymerization shrinkage, does.

The small number of restorations available for evaluation at the six-year recall may have masked differences that could have been seen if a higher percentage of the restorations had been available for evaluation at six years or if the number of restorations in the study had been greater. Although this study ended after the six-year recall, it would be interesting to see if the bonded restorations continued to perform well over a long period of time.

CONCLUSIONS

Amalgambond Plus with HPA powder retained complex amalgam restorations well at six years. In view of this and other studies, the bonding of amalgam restorations appears to be a viable alternative to mechanically retained restorations.

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Laboratory Research

Wear Behavior of New Composite Restoratives

AUJ Yap • CH Tan • SM Chung

Clinical Relevance

The wear resistance of new nanofill and ormocer composites may be comparable or superior to polyacid-modified, microfill and minifill composites.

SUMMARY

This study investigated the wear resistance of recently introduced nanofill (Filtek Supreme [FS], 3M-ESPE) and ormocer (Admira [AM], Voco) composites and compared their wear characteristics to microfill (Filtek A110 [AO], 3M-ESPE]), minifill (Esthet X [EX], Dentsply; Filtek Z250 [ZT], 3M-ESPE) and polyacid-modified (Dyract AP [DY], Dentsply) composites. Six specimens were made for each material. The specimens were conditioned for one week in distilled water at 37°C and subjected to wear testing at 20 MPa contact stress against SS304 counter-bodies using reciprocal compression-sliding wear instrumentation. Distilled water was used as lubricant. Wear depth (µm) was measured using profilometry every 5,000 cycles up to 20,000 cycles. The results were analyzed using ANOVA/Scheffe's test ($p<0.05$). Wear of the materials was cycle and fatigue dependent. Although no significance in wear was observed between materials after 5,000 cycles of wear testing, significant differences were observed at 10,000 cycles and greater. After 20,000 cycles of wear testing, ranking was as follows: ZT > DY > AM > AO > FS > EX. Wear ranged from 39.90 µm for EX to 113.32 µm for ZT. The wear resistance of ZT and DY was significantly lower than AO, FS and EX. In addition, ZT experienced significantly more wear than AM. Under the conditions of this *in-vitro* study, the wear resistance of nanofill and ormocer composites was comparable or superior to polyacid-modified, microfill and minifill composites.

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INTRODUCTION

Composites are three-dimensional combinations of at least two chemically different materials with a distinct interface (Phillips, 1981). This merger produces materials with properties that could not be achieved from any individual components alone. Dental composites are essentially comprised of a resin matrix (organic phase), filler-matrix coupling agent (interface), filler particles (dispersed phase) and other minor additives including polymerization initiators, stabilizers and coloring pigments. There is good evidence that dental composites can provide excellent service in Class I and II cavities with minimal direct stress (Bayne, Heymann & Swift, 1994; Mair, 1998; Gaengler, Hoyer & Montag, 2001; Turkun & Aktener, 2001). While early composites wore at rates of 50 to 75 µm per year, newer composites have significantly lower wear rates of 10 to 20 µm per year (Leinfelder & others, 1986; Bayne & others, 1994). The improvement in wear resistance was achieved by using different fillers and smaller average filler particle sizes. Despite the improvement in wear resistance,

wear continues to be a problem in stress-bearing situations (Gohring, Besek & Schmidlin, 2002). Clinical studies have shown that occlusal contact area (OCA) or attritional wear can exceed contact free abrasive wear by three to five times (Lutz & others, 1984). Changes may develop in functional occlusion if OCA wear is of sufficient magnitude.

Dental composites based on nanofill and ormocer (organically modified ceramics) technologies were recently introduced to the dental profession. Nanofill composites were mentioned in the early 1990s (Bayne & others, 1994), but the first commercial product (Filtek Supreme, 3M-ESPE) was launched in late 2002. The incisal (translucent) shades of Filtek Supreme contain a combination of non-agglomerated 75 nm silica nanofillers and aggregated silica nanocluster (with a primary particle size of 75 nm) fillers. The cluster size ranges from 0.6 to 1.4 μm and filler loading is approximately 57% by volume. All other shades (body, enamel and dentin) contain a combination of non-agglomerated 20 nm nanosilica and aggregated zirconia/silica nanoclusters (with primary particle sizes from 5 to 20 nm). The cluster particle size range is 0.6 to 1.4 μm and filler loading is about 59% by volume. The technology used in the ormocer material (Admira, Voco) is somewhat different from conventional composites. While the latter are based on a purely organic matrix, ormocer consists of an inorganic-organic (inorganic backbone based on SiO_2 functionalized with polymerizable organic units) network matrix formed through polycondensation. The filler particles are imbedded in this cross-linked inorganic and organic network matrix. Average particle size is 0.7 μm, which is comparable to most minifill composites.

Independent scientific literature on the OCA wear resistance of nanofill and ormocer composites is generally lacking (Manhart & others, 2000).This study investigated the wear resistance of these new composite materials and compared their wear behavior to microfill, minifill and poly-acid-modified composites.

METHODS AND MATERIALS

Table 1 shows the materials evaluated, their manufacturers, lot numbers and cure times. All materials were shade A2. The restorative materials were placed in the rectangular recesses (8 mm long x 4 mm wide x 2 mm deep) of customized acrylic molds and covered with acetate strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was then placed over the molds and pressure applied to extrude excess material. The composite restoratives were then light polymerized according to manufacturers' cure time through the glass slide using a Spectrum Curing Light (Dentsply Inc, Milford, DE, USA). The mean intensity of the curing light (417 ± 10 mW/cm^2) was determined with a commercial radiometer (CurRite, EFOS Inc, Ontario, Canada) prior to the start of the experiment. Immediately after light polymerization, the acetate strips were discarded and the materials stored in distilled water for one week at 37°C.

The wear instrumentation used was a reciprocating compression-sliding system in which the material specimens were moved back and forth against a loaded counter-body. The instrumentation utilized a crank-and-slider mechanism, whereby the rotary action of an induction motor was translated into linear motion of the sliding platform. One complete circle drawn by the crank translated to one complete horizontal motion of the platform, comprising a forward and backward stroke of 3 mm each. Details of the wear instrumentation have been described in previous papers (Yap & others, 2001; Yap, Teoh & Chew, 2002a). The restorative materials were subjected to wear testing against circular, flat-ended AISI SS304 stainless steel abrading counter-bodies 1-mm in diameter at 100 cycles/minute with distilled water as lubricant. Prior to usage, the stainless steel abrading counter bodies were finished with a series of sandpapers ranging from 600 to 1200 grit to standardize the contact surfaces. A constant stress (σ) of 20 MPa was maintained throughout the experiment with the use of a 1.6 kg load (P) based on the formula:

$$P=(\sigma \times A)/a$$

Table 1: *Composite Materials Evaluated*

Material	Category	Manufacturer	Batch #	Shade Cure Time
Filtek A110	Microfill	3M-ESPE, St Paul, MN, USA	200011128	A2 40 seconds
Esthet X	Minifill	Dentsply, Konstanz, Germany	020607	A2 20 seconds
Filtek Z250	Minifill	3M-ESPE, St Paul, MN, USA	20010306	A2 20 seconds
Dyract AP	Poly-acid modified	Dentsply, Konstanz, Germany	02070062	A2 40 seconds
Filtek Supreme (Body)	Nanofill	3M-ESPE, St Paul, MN, USA	EXM #612	A2 20 seconds
Admira	Ormocer	Voco, Cuxhaven, Germany	025801	A2 40 seconds

Table 2: *Mean Wear of the Materials at the Various Wear Intervals*

Materials	Number of Wear Cycles			
	5,000	10,000	15,000	20,000
Filtek A110	27.85 (8.92)	31.92 (9.66)	43.02 (14.12)	52.38 (18.10)
Esthet X	21.23 (7.59)	25.65 (6.51)	31.43 (8.04)	39.90 (10.62)
Filtek Z250	36.47 (3.54)	61.97 (6.51)	86.90 (18.68)	113.32 (28.72)
Dyract AP	37.58 (18.44)	56.63 (18.04)	74.98 (17.36)	94.68 (14.35)
Filtek Supreme	26.32 (5.12)	34.60 (9.49)	41.68 (13.25)	48.57 (15.93)
Admira	24.87 (3.30)	47.27 (10.94)	60.23 (15.15)	70.07 (13.39)

Standard deviation in parentheses.

Table 3: *Results of Statistical Analysis*

Number of Wear Cycles	Differences
5,000	No significant difference
10,000	Dyract > Filtek A110, Esthet X Filtek Z250 > Supreme, Filtek A110, Esthet X
15,000	Filtek Z250, Dyract > Filtek A110, Supreme, Esthet X
20,000	Filtek Z250, Dyract > Filtek A110, Supreme, Esthet X Filtek Z250 > Admira

Results of one-way ANOVA/Scheffe's test ($p<0.05$). > indicates statistical significance in mean wear.

where A is the nominal circular contact area (πr^2) of 0.79 mm^2 and a is the gravitational acceleration (9.81 mm/s^2) of the load.

Material wear (maximum depth of wear track) was measured using profilometry (Surftest SV-400, Mitutoyo, Kanagawa, Japan) along the width of the specimens at the center of the wear track, which was localized with markers. A vertical magnification of 100x and a horizontal magnification of 20x were employed for profilometry. The travel length of the stylus was set at 3 mm and the adjacent unworn areas were used as references. Wear measurements were taken at the center of the wear track at every 5,000 cycles up to 20,000 cycles. Interaction between the materials and the number of cycles was determined using two-way ANOVA. Comparison between materials was done using one-way ANOVA and Scheffe's post-hoc test at significance level 0.05.

RESULTS

Table 2 and Figure 1 show mean wear of the composite restoratives at various wear intervals. Table 3 shows the results of statistical analysis. For all materials, wear was greatest during the initial 5,000 cycles of testing. At all wear intervals, the lowest wear was observed with Esthet X. After 5,000 cycles of testing, wear ranged from 21.23 µm for Esthet X to 37.58 µm for Dyract. After 20,000 cycles, wear ranged from 39.90 µm for Esthet X to 113.32 µm for Filtek Z250. The ranking of wear resistance after 20,000 cycles of testing was as follows: Esthet X > Supreme > A100 > Admira > Dyract > Filtek Z250.

Two-way ANOVA revealed significant interactions between materials and the number of cycles. The OCA wear of the composites was therefore cycle dependent. Although material wear was not statistically different after 5,000 cycles of testing, significant differences were observed from 10,000 wear cycles onward. At 10,000 cycles, the wear of Dyract and Filtek Z250 was significantly greater than Filtek A110 and Esthet X. In addition, the wear of Filtek Z250 was significantly greater than Supreme. After 15,000 cycles of testing, Dyract and Filtek Z250 experienced significantly more wear than Filtek A110, Supreme and Esthet X. The results of statistical analysis at 20,000 cycles were identical to that at 15,000 cycles with the exception of a significant difference between Filtek Z250 and Admira.

DISCUSSION

OCA wear results from direct opposing tooth contact during bruxism and indirect contact through trapped food particles during the closed phase of mastication (Mair & others, 1996). Direct tooth contact may also occur during mastication (Anderson & Picton, 1957), especially in the final stages just prior to swallowing, where contact can occur in every stroke (Adams & Zander, 1964). A 20 MPa contact stress was used, as values ranging from 3.9 to 17.3 MPa have been reported during mastication (Anderson, 1956). An acetate finish, the smoothest for composite restoratives (Yap, Lye & Sau, 1997), was selected to avoid discrepancies associated with using rotary finishing/polishing procedures. It also provided for a worse-case scenario, where a matrix or polymer-rich surface is exposed. Water was chosen as the storage and wear medium, as it has been shown to produce the greatest wear for most composite materials (Yap & other, 2002b). The one week storage period allowed for composite post-cure (Yap, 1997) and elution of all leachable components from the materials (Ferracane & Condon, 1990).

A stainless steel counter-body was used based on a study by McKinney and Wu (1982). Briefly, enamel and enamel-like antagonists tend to polish composite surfaces, producing little wear. Softer counter-body materials like stainless steel are abraded by the inorganic filler particles, producing a rough contact surface which, theoretically, wears the composite matrix preferentially. This results in a "plucking" effect in which the unworn filler particles are completely removed. The

"plucking" wear pattern has been observed clinically on posterior composite restorations (Abell, Leinfelder & Turner, 1983). As OCA wear is also caused by indirect contact through trapped food particles, a more relevant counter-body should be softer than enamel and have a hardness closer to that of hard foods. In addition, the OCA wear observed with bruxism is the sum result of slurry wear during mastication and sliding wear during the bruxing event (Yap & others, 2001). Using cylindrical stainless steel bodies also enabled contact stress to be standardized throughout the experiment.

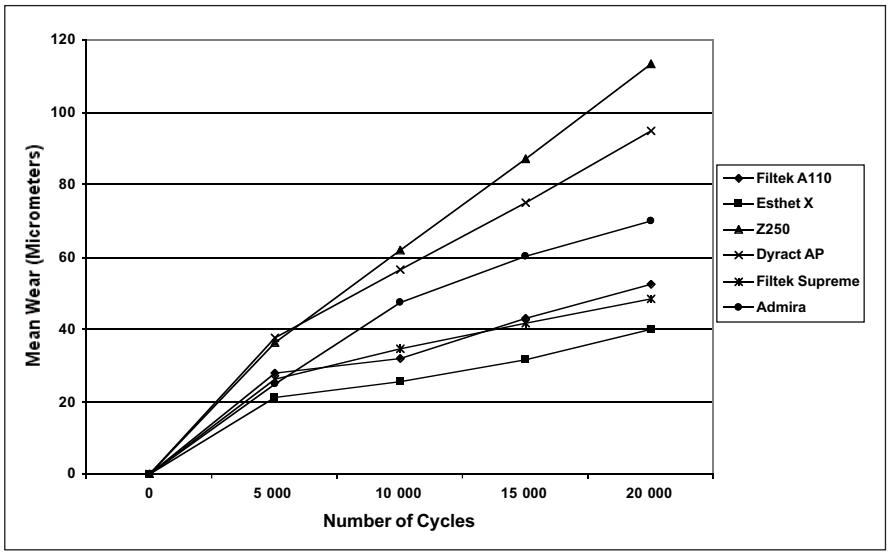

Figure 1. *Mean wear of composite restoratives.*

No significant difference in wear was observed between materials during the initial 5,000 cycles of wear testing. This may be attributed to the high wear rates observed for all materials during this wear period (Figure 1). The latter can be explained by the fact that the composite restoratives were polymerized under pressure against acetate strips and not finished. This resulted in matrix rich surfaces with lower wear resistance, leading to the high wear rates observed. The matrix rich layer was removed during initial wear testing and subsequent data was more predictive of material wear behavior. For the remaining wear intervals, differences in composite wear behavior can be explained by disparities in microstructures and filler types/volume. Composite wear has been shown to decrease with increased filler loading (Condon & Ferracane, 1997; Lim & others, 2002). In spite of its relatively high filler loading (60% volume), the wear resistance of Filtek Z250 was significantly lower than most of the other composites evaluated after extended wear testing (10,000 to 20,000 cycles). The significantly lower wear resistance of Filtek Z250 may be caused by fatigue wear mechanisms. Fatigue is the general phenomenon of material failure after several cycles of loading to a stress level below the ultimate tensile stress (Shackelford, 1996). Fatigue wear occurs as a result of formation and propagation of subsurface microcracks when two surfaces move under dynamic load (Mair, 1992). Fatigue wear, together with the related process of delamination, has been reported in dental composites (Hu, Marquis & Shortall, 1999; Yap & others, 2002a). The phenomenon, however, seems to occur only in dental composites containing very hard zirconia fillers like Z100 and Filtek Z250. These fillers tend to transmit rather than absorb stresses generated during wear testing (Yap & others, 2002a).

The wear resistance of Dyract was significantly lower than Supreme and Esthet X. This may be explained by the lower filler loading of Dyract (47% volume) as compared to Supreme (59% volume) and Esthet X (60% volume). Dyract's low wear resistance could also partially contribute to using different polymers for the organic phase. Dyract's polymer matrix is based on urethane dimethacrylate and TCB (reaction product between butane tetracarboxylic acid and HEMA [Hydroxyethyl methacrylate]), while most of the other composites were based on BisGMA (Bisphenol A glycidyl methacrylate), BisEMA (ethoxylated BisGMA) and TEGDMA (Triethylene glycol dimethacrylate). TCB is specifically designed to uptake water which is needed for activation of the acid-base reaction within the polymer matrix (Yap & others, 2000). The plasticizing effect of water may also explain the significantly lower wear resistance of Dyract as compared to Filtek A110, despite Filtek A110's lower filler loading (40% volume). The use of polyacid-modified resin composites in stress-bearing situations is therefore not recommended.

At all wear intervals, the lowest wear was observed with Esthet X. This could be attributed to Esthet X's high filler loading and the use of silicon dioxide and softer barium alumino-fluorosilicate fillers. Composites are biphasic, with one phase (fillers) embedded into the other (resin/polymer matrix). With microfill composite (Filtek A110), there is simultaneous loss of both phases due to the extremely small particle sizes (Yap & others, 2001). A relatively smooth surface is maintained, which minimizes friction and wear. This accounts for the low wear observed with Filtek A110, which corroborated the results of previous clinical and laboratory studies (Lambrechts, Braem & Vanherle, 1987; Yap & others, 2001). In view of the smaller particle size of the nanofill composite (Supreme) (20 nm as compared to 40 nm for microfillers), better wear resistance is anticipated. This was generally observed in this study, although the difference in wear was not statistically significant.

Despite their good wear resistance, microfill composites should not be used in stress-bearing situations due to their low fracture resistance, stiffness and fatigue strength as compared to heavier filler composites (Drummond, 1989; Willems & others, 1992; Braem & others, 1994). Nanofill composites have not been independently characterized with regard to these mechanical properties. Manhart and others (2000) reported that the wear rate of an ormocer composite (Definite, Degussa, Hanau, Germany) was lower or comparable to packable minifill composites. This was supported by the findings of this study.

CONCLUSIONS

Under the conditions of this *in-vitro* study:

1. The wear behavior of composite restoratives is cycle dependent.
2. The wear resistance of Filtek Z250 was significantly poorer than Filtek A110, Filtek Supreme and Esthet X after 10,000 to 20,000 cycles of wear testing. After 20,000 wear cycles, Filtek Z250 also had significantly more wear than Admira.
3. The wear resistance of Dyract AP was also significantly lower than Filtek A110, Filtek Supreme and Esthet X.
4. The wear resistance of nanofill and ormocer composites was comparable or superior to polyacid-modified, microfill and minifill composites.

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Finishing/Polishing of Composite and Compomer Restoratives: Effectiveness of One-step Systems

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Clinical Relevance

For composite and compomer restoratives, surface finish obtained with Pogo and Sof-Lex Brush was comparable or superior to that of two and multi-step finishing/polishing systems.

SUMMARY

This study investigated the surface texture of composite (Z100, 3M ESPE) and compomer (F2000, 3M ESPE) restoratives after treatment with different one-step finishing/polishing systems (One-Gloss [OG], Shofu; PoGo [PG], Dentsply; Sof-Lex Brush [SB], 3M ESPE). The surface roughness obtained was compared to that using a matrix strip [MS], a two-step rubber abrasive (CompoSite [CS], Shofu) and a graded abrasive disk (Super Snap [SS], Shofu) system. Eight specimens (3-mm long x 3-mm wide x 2-mm deep) of each material were made according to manufacturer's instructions. With exception of the MS group, all groups were roughened with 320 grit grinding paper using a lapping device prior to finishing/polishing with the different systems. The mean surface roughness (μm) was measured with a profilometer. Data was subjected to ANOVA/Scheffe's tests and independent samples *t*-test at significance level 0.05. Mean Ra ranged from 0.22 to 0.32 μm for Z100 and 0.45 to 0.68 for F2000. For both materials, the smoothest surfaces were obtained with MS. The roughest surfaces were observed after treatment with SS and OG for Z100 and F2000, respectively. The effectiveness of the finishing/polishing systems was material dependent. The surface finish produced by PG and SB was superior or comparable to that obtained with CS, SS and OG.

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INTRODUCTION

The clinical use of composite and compomer restoratives has increased substantially over the past few years due to increased aesthetic demands by patients, improvements in formulation and simplification of bonding procedures. Composites are recommended for restoring all cavity classes in anterior and posterior teeth, while compomers are generally indicated for use

in non-stress bearing areas. Regardless of the cavity class and location, a smooth surface finish is clinically important, as it determines the aesthetics and longevity of composite and compomer restorations. The presence of surface irregularities arising from poor finishing/polishing techniques and/or instruments can create clinical problems such as staining, plaque retention, gingival irritation and recurrent caries (Larato, 1972; Chan, Fuller & Hormati, 1980; Dunkin & Chambers, 1983; Shintani & others, 1985). Well finished/polished restorations are also more easily maintained (Strassler & Bauman, 1993). For composite and compomer restoratives, curing against a matrix results in the smoothest surface possible (Yap, Lye & Sau, 1997). Despite careful placement of matrixes, some degree of finishing (gross contouring) and polishing (reduction of roughness and scratches caused by finishing instrument) of restorations is usually necessary. This inevitably violates the smoothness achieved with a matrix (Bauer & Caputo, 1983; Yap & others, 1997).

Table 1: *Technical Profiles of the Materials Evaluated*

Material	Resin/Filler	Filler Size (mm)	Filler Content Volume %	Lot #	Manufacturer
Z100	*Resin:* BIS-GMA TEGDMA *Filler:* Zirconia Silica	0.01 – 3.5	66	20010208	3M ESPE, St Paul, MN, USA
F2000	*Resin:* CMDA GDMA *Filler:* Silica FAS	3 - 10	67	20010122	3M ESPE, St Paul, MN, USA

CDMA = Dimethacrylate functional oligomer derived from citric acid
GDMA = Glyceryl methacrylate
FAS = Fluoroalumino silicate glass

Table 2: *Finishing/Polishing Systems and Sequences*

Finishing/Polishing System	Usage	Handpiece Speed	Manufacturer
Super–Snap			
Coarse	Dry, 6 strokes	12,000 rpm	Shofu Inc, Kyoto, Japan
Medium	Dry, 6 strokes	12,000 rpm	
Fine	Dry, 6 strokes	12,000 rpm	
Extra-Fine	Dry, 6 strokes	12,000 rpm	
CompoSite Polishers			
CompoSite	Wet, 12 strokes	12,000 rpm	Shofu Inc, Kyoto, Japan
CompoSite Fine	Dry, 12 Strokes	12,000 rpm	
One-Gloss	Wet, 12 heavy strokes Wet, 12 light strokes	10,000 rpm 10,000 rpm	Shofu Inc, Kyoto, Japan
Pogo	Dry, 24 light intermittent strokes	12,000 rpm	Dentsply, Konstanz, Germany
Sof-Lex Brush	Dry, 24 strokes	12,000 rpm	3M ESPE, St Paul, MN, USA

Although the effect of finishing/polishing systems on surface roughness of composites has been widely reported in the literature (Yap & others, 1997; Hoelscher & others, 1998; Setcos, Tarim & Suzuki, 1999; Roeder, Tate & Powers, 2000; Marigo & others, 2001), similar studies on compomers are relatively limited (Yap & others, 1997; Bouvier, Duprez & Lissac, 1997). Most of these studies involved multi-/two-step systems and concluded that multi-step systems gave the smoothest surface finish. To reduce cost and clinical time, one-step finishing/polishing systems were recently introduced to the dental profession. The effectiveness of these systems needs to be independently validated and researched. Instead of using abrasives of increasing fineness, these systems generally employ varying and intermittent pressure for finishing and polishing.

This study determined the surface roughness of composite and compomer restoratives after treatment with three one-step finishing/polishing systems (One Gloss, Shofu, Kyoto, Japan; Pogo, Dentsply, Konstanz, Germany; Sof-Lex Brush, 3M ESPE, St Paul, MN, USA). The surface roughness obtained with these new systems was compared to that using a matrix strip, a two-step rubber abrasive (CompoSite, Shofu) and a graded abrasive disk (Super Snap, Shofu) system.

METHODS AND MATERIALS

Table 1 shows the technical profiles of the composite and compomer restoratives used in this study. The materials, packed into the square recesses (3-mm long x 3-mm wide x 2-mm deep) of customized acrylic molds, were covered with matrix strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was then

placed over the molds and pressure applied to extrude the excess material. The materials were then light polymerized for 40 seconds through the glass slide to standardize curing distance (1 mm). The intensity of the light source (Trilight, 3M ESPE, Seefeld, Germany) was determined with the in-built radiometer and a constant output of 800 mW/cm^2 was established. Forty-eight specimens of each material were made and divided into six groups of eight specimens. Specimens in Group 1 were left alone (matrix strip [MS] finish), while the remaining groups were subjected to gross finishing with ANSI (American National Standards Institute) 320 grit grinding paper (Carbimet disks; Wirtz-Buehler, Dusseldorf, Germany) using a lapping device (Phoenix Beta; Wirtz-Buehler, Dusseldorf, Germany) at 300 rpm for one minute. The groups were then finished/polished with the following systems: Group 2—Super Snap [SS]; Group 3—CompoSite [CS]; Group 4—One Gloss [OG]; Group 5—PoGo [PG] and Group 6—Sof-Lex Brush [SB]. Table 2 shows the details of the finishing/polishing sequences and procedures.

After finishing/polishing, the mean surface roughness (μm) of the specimens was measured using a profilometer (Surftest SV-400; Mitutoyo, Kanagawa, Japan). Readings were taken at the center of each specimen, and four sampling lengths of 0.25 mm were used, giving a total evaluation length of 1 mm. All statistical analysis was carried out at significance level 0.05. Two-way ANOVA was used to determine significant interactions between the independent variables (materials and finishing/polishing techniques). 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 sample *t*-tests were employed to evaluate differences between the two materials.

RESULTS

Table 3 shows the mean surface roughness observed with the different finishing/polishing systems. Results of statistical analysis are shown in Table 4. Mean Ra ranged from 0.22 to 0.32 μm for Z100 and 0.45 to 0.68 for F2000. Results of two-way ANOVA revealed significant interactions between the materials and finishing/polishing systems. The effect of the finishing/polishing systems on surface roughness was therefore material dependent. For both materials, the smoothest surfaces were obtained with MS. The roughest were observed after treatment with SS and OG for Z100 and F2000, respectively. Ra values obtained with the use of MS were significantly lower than those values observed after treatment with all finishing/polishing systems. For Z100, no significant difference in Ra values was observed between the different finishing/polishing systems. For F2000, treatment with PG and SB resulted in significantly lower Ra values than treatment with CS, SS and OG. For all treatment groups, Ra values observed with F2000 were significantly greater than Z100.

DISCUSSION

Improper application of finishing/polishing instruments could lead to decreased effectiveness and less than optimal results (Kanter, Koski & Bogdan, 1983; Joniot & others, 2000). Strict adherence to manufacturers' instructions on finishing/polishing procedures was thus observed. Efforts were also made to standardize the different aspects of the methodology, including handpiece speed and the total number of strokes employed for each finishing/polishing system. The slight variations of Ra values within each treatment group may be accounted for by the unequal distribution of abrasives in the delivery medium and the differences in pressure exerted during finishing/polishing procedures. The latter was minimized by using a single operator for the experiment. The term finishing/polishing was employed in place of finishing and polishing, as the two processes are inter-related and cannot be easily demarcated.

In this study, the smoothest surfaces were obtained by curing both materials against a matrix strip. This finding was in agreement with previous studies on resin composites (Yap & others, 1997; Hondrum & Fernandez, 1997). The smoothness obtained with matrix strips [MS] could not be reproduced by any of the finishing/polishing systems. As Ra values after

Table 3: *Mean Surface Roughness (Ra) After Treatment with the Different Finishing/Polishing Systems*

Finishing/Polishing System	Z100	F2000
Matrix strip [MS]	0.04 (0.01)	0.05 (0.01)
Super-Snap [SS]	0.32 (0.13)	0.63 (0.09)
CompoSite [CS]	0.24 (0.03)	0.63 (0.14)
One-Gloss [OG]	0.31 (0.07)	0.68 (0.08)
Pogo [PG]	0.22 (0.08)	0.45 (0.08)
Sof-Lex Brush [SB]	0.22 (0.04)	0.47 (0.08)

Standard deviations in parentheses.

Table 4: *Comparison of Mean Surface Roughness Between Finishing/Polishing Systems*

Materials	Differences
Restorative Z100	Matrix strip < Pogo, Sof-Lex Brush, CompoSite, One Gloss, Super-Snap
Restorative F2000	Matrix strip < Pogo, Sof-Lex Brush < CompoSite, Super-Snap, One Gloss

Standard deviations in parentheses.

treatment with the various finishing/polishing systems were generally greater than the critical threshold surface roughness for bacteria adhesion of 0.2 µm (Bollen, Lambrechts & Quirynen, 1997), the results of this study are clinically relevant. While no further reduction in bacterial accumulation is expected below this threshold value, any increase in surface roughness above 0.2 µm results in a simultaneous increase in plaque accumulation and increases the risk for periodontal inflammation and caries (Bollen & others, 1997).

The effect of finishing/polishing systems on surface roughness was material dependent. In earlier studies, the use of graded aluminum oxide disks has been shown to give the best surface finish for resin composites (Yap & others, 1997; Hoelscher & others, 1998; Setcos & others, 1999). The technology for two- and one-step finishing/polishing systems has evolved over the last few years and current systems appear to be as effective as multi-step systems for finishing and polishing dental composites. With the exception of PG, all finishing/polishing systems evaluated used aluminum oxide as the abrasive. Differences between products include variations in abrasive size/shape, configuration (wheel, points and cups) and abrasive delivery medium. Although these new systems are extremely effective for highly filled hybrid composites such as Z100, their utility on microfill composites warrants further investigation in view of the differences in filler particle sizes (Jefferies, 1998).

Compomers are basically composites that contain either or both essential components of glass ionomer cements (fluoroalumino silicate glasses and acidic polymers) but at a level insufficient to promote an acid-base reaction in the dark (McLean, Nicholson & Wilson, 1994). They were developed to combine the major advantages of composites (easy handling and aesthetics) and glass ionomer cements (fluoride release and chemical bonding to tooth). Bouvier and others (1997) reported that the smoothest compomer surface was obtained using graded aluminum oxide disks. In this study, the use of PG and SB resulted in significantly smoother surfaces compared to the graded aluminum oxide disk system SS. Ra values obtained with PG and SB were also significantly lower than those for CS and OG. The superior performance of PG may be partially attributed to the use of fine diamond powders instead of aluminum oxide and the cured urethane dimethacrylate resin delivery medium. However, PG is only available in disk configuration. Its clinical use for finishing/polishing cervical restorations with margins located at or below the gingival crest may not be feasible as it can result in severe gingival trauma. SB was developed for finishing/polishing the concave and convex anatomy found on posterior restorations. The results of this study suggest that SB can also be used for anterior restorations. SB is made from aluminum oxide containing thermoplastic polyester elastomer and is fashioned after the shape of a prophylaxis brush. The superior performance of SB could be attributed to the ability of the soft polyester bristles to conform to restoration surfaces and the unique abrasive delivery medium. The use of OG resulted in the roughest surface for F2000. This one-step system also produced the roughest surface finish for resin-modified glass ionomer cements (Yap & others, 2002). In addition to aluminum oxide, OG also employs silicon dioxide as an abrasive. Polyvinylsiloxane is the delivery medium for the abrasives. Due to its high elasticity, the polyvinylsiloxane delivery medium may be resistant to wear by the relatively soft fluorosilicate glasses used in compomers, thus, leading to reduced efficiency of the abrasives.

Regardless of treatment groups, the surface finish of Z100 was significantly better than F2000. Harder filler particles are left protruding from the surface during finishing/polishing as the softer resin matrix is preferentially removed. Materials with larger filler particles are therefore expected to have higher Ra values after finishing/polishing. The filler particle size of Z100 ranged from 0.1 µm to 3.5 µm, while that of F2000 ranged from 3 µm to 10 µm. In view of the aforementioned, the significantly higher Ra values observed with F2000 after finishing/polishing is expected. Results of this study support the use of one-step systems for finishing and polishing composite and compomer restoratives. The use of these systems resulted in similar or superior surface finish when compared to multi-/two-step systems. In view of the time and cost savings, the use of one-step finishing/polishing systems is recommended. Further investigations could incorporate a spectrum of composite and compomer materials and the determination of surface gloss produced by one-step systems.

CONCLUSIONS

Within the limitations of this study:

1. The use of matrix strips provided the smoothest surfaces for composite and compomer materials.
2. The effect of finishing/polishing systems on surface roughness was material dependent.
3. For the composite material (Z100), no significant difference in surface roughness was observed between one-, two- and multi-step finishing/polishing systems.
4. For the compomer material (F2000), Pogo disks and Sof-Lex Brush provided significantly smoother surfaces than the other finishing/polishing systems including graded abrasive disks.

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Staining of Non-carious Human Coronal Dentin by Caries Dyes

DW Boston • J Liao

Clinical Relevance

Although the caries dyes used in this study frequently stained areas of non-carious dentin, the results suggest that this staining can be differentiated from more intensely stained carious dentin, especially in the main body of dentin within the tooth crown.

SUMMARY

This study tested the hypothesis that commercially available caries dyes stain non-carious human coronal dentin in freshly extracted teeth. Multiple sections were cut from 10 non-carious and two control carious teeth using a water-cooled saw. Each section was stained with one of five caries dyes. The location of staining, if any, was noted and the staining intensity was scored on a four-point scale. One of the sections from each tooth was subsequently decalcified and processed for observation under a light microscope using four histologic staining techniques to evaluate morphology, collagen distribution and bacterial content. The association between the stain intensity scores on the undecalcified sections and the five dyes was evaluated using the Kruskal-Wallis One-Way ANOVA by Ranks test. Outer carious dentin in the control specimens stained intensely with each of the five dyes. In the undecalcified, non-carious sections, all had at least one area of staining. However, this staining could be differentiated from the intensity of dye staining in the carious controls, except in two instances. The association between stain intensity scores and the five dyes was not statistically significant. In the histologic sections, numerous bacteria were seen within the dentinal tubules of carious lesions of the two control specimens; however, no bacteria were found in any of the sections from non-carious specimens. Histologically, no differences were observed in the morphology or staining pattern within mantle or circumpulpal dentin in areas stained with caries dye, and in only one unique instance within the main body of the dentin. These results suggest that the five dyes evaluated in this study can stain non-carious dentin, however, this stain can be differentiated from the staining of outer carious dentin *in vitro*.

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INTRODUCTION

Carious dentin consists of outer and inner layers that can be differentiated using dentin caries dye. Outer car-

ious dentin is greatly softened, highly infected, not remineralizable and stainable with 1.0% sulforhodamine B in propylene glycol (Fusayama, 1979). By contrast, inner carious dentin is only somewhat softened, not infected or less infected, remineralizable and not stainable with caries dye. It was also found that non-carious dentin reportedly does not stain with caries dye (Fusayama, 1979, 1993). The mechanism of this differential staining is related to acid-mediated changes in dentin collagen and not directly to bacterial infection or demineralization (Kuboki, Liu & Fusayama, 1983). A clinical guide for the selective removal of outer carious dentin suggests applying the dye solution followed by selective excavation of the dye-stainable dentin, repeating the process until a non-staining endpoint is obtained (Fusayama, 1988). To reduce the subjective judgement required for the removal of carious dentin, caries dye can be used to visually differentiate the outer carious dentin (List & others, 1987). At least five commercially available dye solutions have been developed to disclose outer carious dentin, with dye and/or solvent varying from product to product.

More recently, concern has been raised about the specificity of dentin caries dyes in differentiating carious from normal dentin. In one *in vitro* study (Yip, Stevenson & Beeley, 1994), caries dye staining was found on clinically hard cavity walls after traditional excavation of carious dentin and on the walls of cavities prepared in non-carious teeth. Areas of sound dentin, including those adjacent to the dentinoenamel junction and the pulp chamber on sections of carious teeth, also stained in this study. The authors conclude that 0.5% basic fuschin and 1% sulforhodamine B caries dye solutions lack the "specificity for accurate detection of carious dentin," and they suggest caution in clinical application.

In a clinical study of cavity preparations with clinically hard pulpal walls, more than half the cavity preparations stained with caries dye (Kidd & others, 1989). Even after rinsing and acid etching the dentin subsequent to applying the caries dye in an *in vitro* study of bond strengths, some dye remained on specimen surfaces. In that study, those specimens exposed to caries dye had significantly lower bond strengths to resin composite and compomer when compared to specimens not exposed to caries dye (Demarco & others, 1998).

On the other hand, Re and Summit (1994) have countered these findings by stating that they have never found staining of normal dentin in hundreds of clinical procedures they performed, although this was not based on a scientific study. However, caries dye did not remain on the dentin walls of any Class V cavity in an *in vitro* study of the effects of caries dyes on microleakage (Piva & others, 2002). Similarly, in a laboratory study of 10 Class I cavities prepared in non-carious molars, no staining was found when caries dye was applied (Kidd & others, 1989).

Given these divergent findings and the possible consequences of inadvertently removing non-carious dentin (pulp exposure and weakening of the tooth), several clinically relevant questions arise: Do dentin caries dyes stain areas of normal dentin, and if so, what is the nature of these areas? Are there any differences among the various commercially available dyes in the staining of normal dentin? Are there qualitative differences between the staining of outer carious dentin and normal dentin?

This study tested the hypothesis that commercially available caries dyes stain non-carious human coronal dentin in freshly extracted teeth. Specific aims were: 1) to identify and locate areas of non-carious human coronal dentin that stain with any of five commercially available dentin caries dyes in a set of freshly extracted permanent teeth; 2) to describe areas of stained, non-carious dentin histologically on the basis of morphology, collagen distribution and bacterial content; 3) to determine differences in staining intensity of non-carious dentin among the five commercially available dentin caries dyes and 4) to determine the proportion of false-positive staining scores near the dentinoenamel junction, in the body of the dentin and near the circumpulpal dentin.

METHODS AND MATERIALS

Freshly extracted permanent posterior teeth were obtained from the clinics of Temple University School of Dentistry under a protocol determined to be "exempt" by the Institutional Review Board. Immediately after extraction, each tooth was placed in sterile distilled water at room temperature, then stored at 5˚C for up to three days before use. Each tooth was radiographed after extraction using a source-to-object distance of 16 inches, 70 KVP, 7mA and 14 impulses with D-speed intraoral dental film developed by standard automatic processing. The first 10 teeth to meet the criteria for inclusion in the study were used. The inclusion criteria were based upon visual and radiographic examination. Those teeth accepted had no evidence of restorations, carious lesions, fractures or morphologic anomalies. Teeth with occlusal wear, consisting of very small facets located entirely in enamel, were acceptable. Two additional teeth containing large carious lesions were chosen as controls.

The root(s) of each tooth were cut off 2-3 mm apical to the cemento-enamel junction using a diamond bur in a high speed handpiece with air/water coolant and then discarded. Pulp tissue was dissected from the chamber using a dental explorer. The crowns were mounted in

Resin Rock dental stone (Whip-Mix Corporation, Louisville, KY, USA) for longitudinal sectioning with a low-speed water-cooled saw (VC-50, with #801-137, .014" diamond blade, Leco Corporation, St Joseph, MI, USA). The mounted crowns were kept in 100% humidity during setting of the dental stone and prior to sectioning. Sections of the teeth were used to assess dye staining instead of cavity preparations, so that a maximum amount of dentin could be evaluated, including dentin adjacent to the dentinoenamel junction and dentin adjacent to the pulp chamber, and to optimize visualization. Four serial bucco-lingual longitudinal sections approximately 0.4-mm thick were cut from the mesio-distal center of each tooth. Figure 1 illustrates the sectioning scheme. The sections were placed in labeled, individual plastic containers containing sterile distilled water at room temperature. The block of tooth structure cut away during the beginning of the sectioning process was saved and used for one of the caries dye applications (CD, Table 1), then for histologic analysis. This permitted direct comparisons between histology and dye staining patterns. The remaining block of tooth embedded in stone was discarded after acceptable sections were obtained. Prior to sectioning, staining and scoring the 12 teeth used in this study, a practice set of 11 teeth, five of which were clinically or radiographically carious, were processed. They were sectioned, stained with the five caries dyes and scored only for training purposes.

Five commercially available caries dyes were applied, one per section for each tooth, including the two carious controls. Table 1 lists the dyes and lot numbers. CD dye was applied to the cut surface of the block described above, while the other four dyes were applied to the cut sections. Application and rinsing times followed manufacturers' instructions for each dye. Rinsing was performed at room temperature using a sterile irrigating syringe filled with sterile distilled water. Observations of the location and intensity of any staining were made using a low-power digital microscope (Optem Zoom 100/Olympus DP-11, Hitech Instruments, Edgement, PA, USA) at 20x magnification with reflected incandescent illumination with an opaque background at 640x512 pixel per field resolution. These lighting conditions permitted uniform comparison of the sections and tooth block surfaces since transmitted light was not used. Digital images of selected specimens were produced for further analysis. A four-step ranking for staining intensity was applied to the visual observations: (0)= no staining, (1)= light pastel-shaded staining allowing normal dentin coloration to show through, (2)= intermediate intensity of staining and (3)= deep staining equal to that seen on the carious controls. Staining intensity was scored in three areas per tooth: within approximately 1 mm of the dentino-enamel junction (DEJ Area), within approximately 1 mm of the pulp chamber (Circumpulpal Area) and elsewhere in the dentin (Main Body Area). Figure 2 illustrates these areas. Scoring results from the primary examiner were reviewed with the secondary examiner and differences resolved by consensus.

The block first cut from each specimen was stored in 10% neutral buffered formalin for 48 hours to remove CD dye, then decalcified in 1N formic acid for 10 days. Complete decalcification was confirmed radiographically. The decalcified tissue was returned to 10% neutral buffered formalin and sent for histologic processing. After routine paraffin embedding, 5-micron sections were obtained from the cut surface of each block. For each specimen, separate slides were prepared for four histologic stains. Hematoxylin and eosin were used to reveal pre-dentin, mantle dentin and interglobular

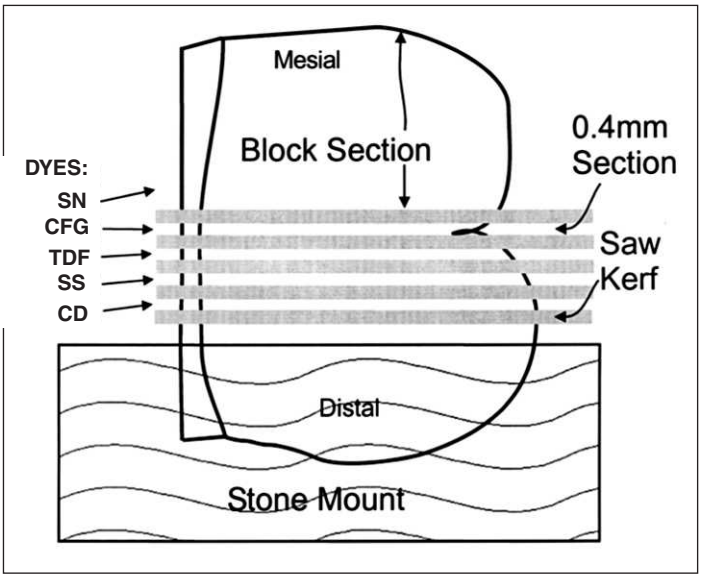

Figure 1: *Sectioning and caries dye-staining scheme for tooth specimens. The tooth crowns are mounted in stone and sectioned to provide an initial block section and four subsequent sections approximately 0.4 mm in thickness.*

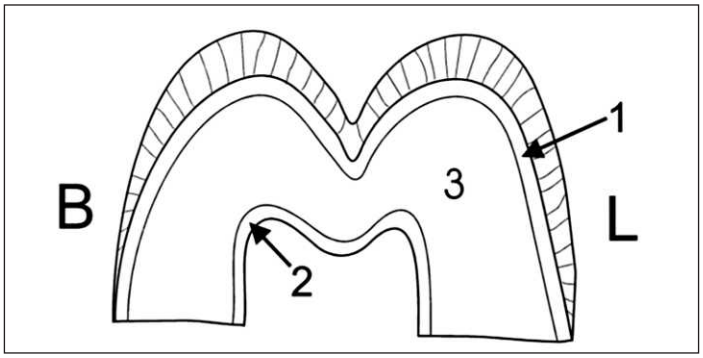

Figure 2: *The three areas of assessment of dye staining are illustrated on a bucco-lingual section obtained from the mounted tooth specimen shown in Figure 1: 1=dentinoenamel junction area, 2=circumpulpal area, 3=main body of dentin area.*

dentin (Mjör, 1966). Silver methenamine was used to reveal pre-dentin and hypomineralized areas (Sogaard-Pedersen, 1985). Collagen was stained with picro-fuschin (McManus & Mowry, 1960) and bacteria were stained with Brown and Brenn gram stain (Sheehan & Hrapchak, 1973). The slides were examined under a light microscope at 40x, 100x and 400x and the staining patterns observed and recorded. The histologic findings for each of the specimens were compared to the CD staining results of the same specimen obtained prior to decalcification.

Table 1: *Dyes and Lot Numbers Used*

CODE	Dye	Lot #	Manufacturer	Composition (Miller, 1998)
CD	Caries Detector	0441A	Kuraray America, Inc, New York, NY, USA	1% acid red 52 in propylene glycol base.
CFG	Caries Finder G	506204	Danville Materials San Ramon, CA, USA	FD&C green dye in propylene glycol base.
TDF	To Dye For	000830	Roydent Dental Products Rochester Hills, MI, USA	Dark red dye in glycerin base.
SS	Sable Seek	2WHM	Ultradent Products, Inc, South Jordan, UT, USA	D&C dark green dye in an aqueous glycol base.
SN	Snoop	001106	Pulpdent Corporation Watertown, MA, USA	Dark blue dye in propylene glycol base.

Table 2: *Number and Percent of Sections Staining at Each stain Intensity Score in Each Section Area, by Dye*

Dye Code	DEJ Area stain intensity scores				Circumpulpal Area stain intensity scores				Main Body Area stain intensity scores			
	0	1	2	3	0	1	2	3	0	1	2	3
CD	5 (50)	2 (20)	3 (30)	0 (0)	7 (70)	0 (0)	3 (30)	0 (0)	2 (20)	8 (80)	0 (0)	0 (0)
CFG	6 (60)	0 (0)	4 (40)	0 (0)	3 (30)	0 (0)	7 (70)	0 (0)	1 (10)	9 (90)	0 (0)	0 (0)
TDF	8 (80)	1 (10)	1 (10)	0 (0)	4 (40)	0 (0)	6 (60)	0 (0)	1 (10)	8 (80)	1 (10)	0 (0)
SS	7 (70)	3 (30)	0 (0)	0 (0)	3 (30)	1 (10)	5 (50)	1 (10)	7 (70)	2 (20)	0 (0)	1[c] (10)
SN[a]	7[b] (78)[b]	1 (11)	1 (11)	0 (0)	2 (22)	2 (22)	5 (56)	0 (0)	2 (22)	7 (78)	0 (0)	0 (0)

[a]SN data based on 9 sections, all others on 10 sections
[b]Number (%) of positive sections
[c]staining due to hollow defect in dentin body of one specimen

The proportion of sections that stained at each intensity score (0,1,2,3) was calculated for each of the five dyes at each of the three locations on the sections. The proportion of positive readings for each dye at each location on the sections was calculated based upon staining scores of 3, then on staining scores of 2 or 3. To test the association between the stain intensity scores and the five dyes for each of the three locations on the sections, the Kruskal-Wallis One-Way ANOVA by Ranks test was performed (IMSL, 1994).

RESULTS

Outer carious dentin in sections of both control specimens was stained intensely with all five dyes, producing an easily discernable demarcation between unstained or very lightly stained inner carious dentin and the intensely stained outer carious dentin. Figure 3 shows Grade 3 staining on a carious control sample stained with CD dye. Each dye produced the color characteristic of its solution (TDF and CD= red; CFG and SS=green; SN=blue), with SS exhibiting the darkest color, a blackish-green.

Table 2 shows the number and percentage of sections that stained at four intensity scores in each of the three areas of sections for the five dyes. Only four usable sections were available from one of the 10-specimen teeth;

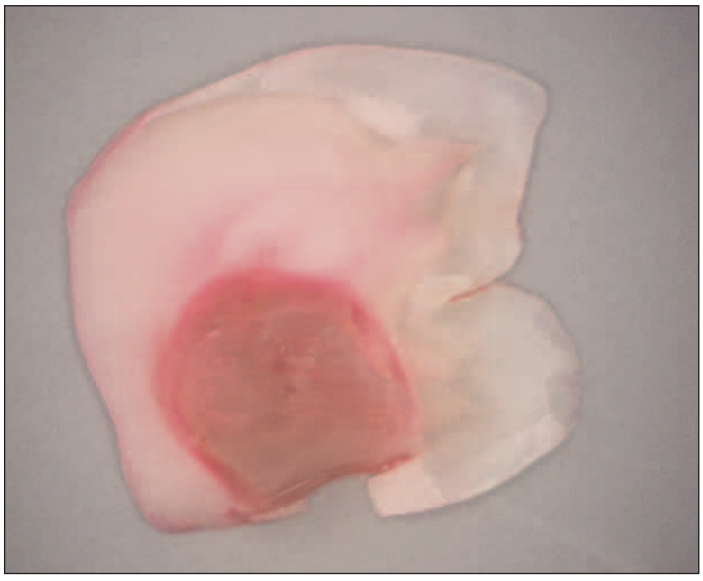

Figure 3: *In this section of a carious control tooth stained with CD dye, the outer carious dentin is stained a deep bright red color, grade 3. Adjacent areas of non-carious dentin are stained a light pastel pink, allowing normal dentin coloration to show through grade 1.*

therefore, the data for SN dye is based upon the staining results from nine sections. Figure 4 shows a non-carious specimen with areas of grade 1 staining immediately adjacent to the pulp and in areas of the main body of dentin. For each of the five dyes, all sections had at least one area of staining. However, this staining could be visually differentiated from intensity of dye staining in the carious controls as indicated by the staining intensity scores, except in two instances. These two sections scored 3 in staining intensity and both were stained with SS: one in the circumpulpal area and the other in the main body area. The 3 score staining in the main body area corresponded to an unusual circular 1.5-mm diameter (spherical, perhaps) hollow dentin defect in the center of the dentin that stained an unusually dark blackish-green. This defect was very localized and appeared to be a developmental phenomenon. For the five dyes, the percentage of stain-free sections ranged from 50% to 80% in the dentinoenamel junction area, from 22% to 70% in the circumpulpal area, to 10% to 70% in the main body of the dentin. Staining in the circumpulpal area was always limited to a very fine line less than 0.5 mm immediately adjacent to the pulp.

When a score of 3 was used as the criterion for false-positive dye staining, only SS produced false-positive readings that resulted in a false-positive proportion of 0.2. When the criterion for false-positive dye staining was lowered to a staining score of 2 or 3, false-positive proportions for the five dyes ranged from 0.5 to 0.8, with CFG and TDF producing the highest and CD the lowest (Table 3). The lowest false-positive proportions were in the main body area, where SN, CFG and CD produced 0 and TDF and SS each produced 0.1. One main body region false-positive was due to the previously mentioned score 3 SS staining defect, and the other was due to a score 2 TDF staining.

The association between the stain intensity scores and the five dyes was not statistically significant for any of the three locations on the sections as determined by the Kruskal-Wallis One-Way ANOVA by Ranks test for circumpulpal area p=0.356, the main dentin body area p=0.065 and the dentinoenamel junction area p=0.477.

In the histologic sections, numerous bacteria were seen within the dentinal tubules of the carious lesions of the two control specimens. The mantle dentin, circumpulpal dentin and main body of non-carious dentin in the controls showed normal morphology but no bacteria, and stained evenly with both the silver methenamine and picrofuschin dyes. In the 10 non-carious specimens, no bacteria were seen regardless of whether the area had stained with CD prior to decalcification and histologic processing. Likewise, no differences in morphology or staining pattern were found in any mantle dentin or circumpulpal dentin. In the main dentin body area of the one tooth that produced a score 3 staining with SS dye, an oval-shaped void approximately 0.02 x 0.03 mm was seen in the hematoxalin and eosin-stained section from this same tooth in the same location as the dentin defect revealed by score 3 staining with SS dye. The histologically observed defect was bacteria-free; the dentinal tubules immediately adjacent to the defect were more widely spaced apart, and about half of the defect was comprised of irregular non-tubular dentin, while the other half was empty. Although this defect was not noticed during visual inspection of the undecalcified CD-stained block from which the histologic section was taken, it probably represents a smaller lateral extension of the defect seen in the SS-stained section of this tooth.

DISCUSSION

In sections of the 10 specimen teeth, all five dyes produced at least one area of staining for each tooth, confirming that non-carious dentin often does stain with dentin caries dyes. However, this stain was discern-

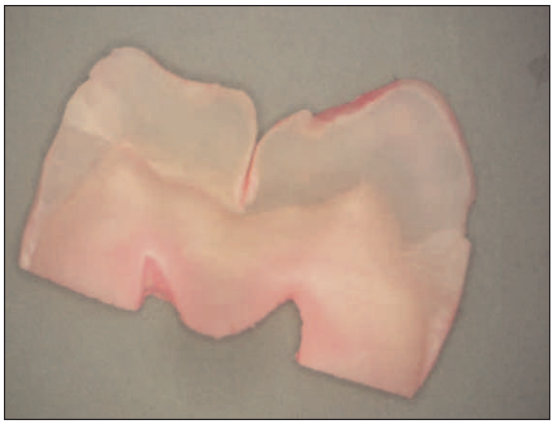

Figure 4: *In this section of a non-carious tooth stained with CD dye, areas of dentin immediately adjacent to the pulp and areas within the main body of the dentin are stained a light pastel pink, grade 1.*

Table 3: *False Positive Proportions Based Upon Staining Scores of at Least 2*

Dye Code	Dentinoenamel Junction Staining	Circumpulpal Staining	Dentin Body Staining	Any Area Staining
SN	.11	.56	0	.67
CFG	.40	.70	0	.80
TDF	.10	.60	.10	.80
SS	0	.60	.10	.70
CD	.30	.20	0	.50

able from the staining intensity obtained on the control areas of carious dentin except in two instances. If the one "3" score SS staining of the dentin defect is discounted as an anomaly, then any staining in the main body of the dentin in all specimen teeth by any of the five dyes studied could always be differentiated from the staining of carious dentin in these specimens.

Although staining observed in the circumpulpal and DEJ areas of the sections always occurred in a very narrow band less than 0.5 mm in width, it was often at a level 2 intensity, suggesting that extra caution is indicated for interpreting staining in these regions. Although this level 2 staining intensity could be differentiated from level 3 staining on the tooth sections in this *in vitro* study, this differentiation may not be possible for actual cavity preparations *in vivo*. While the circumpulpal staining seen in the sections was always immediately adjacent to the pulp chamber and was so thin that in practical terms it would not be encountered until cavity preparation exposed the pulp, the DEJ staining was up to 0.5-mm wide and could present a challenge during normal cavity preparation since this region is always exposed to caries dye application. Of the five dyes, only SS had no level 2 staining intensity scores in the DEJ region, although it did have the highest proportion of level 1 staining intensity in this area (30%).

Staining within the main body of dentin is of particular interest since the largest area of cavity walls is within this region. While the association between the five dyes and the stain intensity scores was not significant for any of the three areas studied, SS dye was the only one to have no level 2 intensity scores in the main body of the dentin and had only the one anomalous 3 intensity score. In the main body of dentin, only TDF produced a level 2 stain intensity score. While all dyes produced level 1 staining in the main body of the dentin (20% to 90%), SS produced the lowest score (20%).

Variation in caries dye staining of non-carious dentin in previous laboratory studies demonstrates that normal dentin will not always stain and, when it does, staining is light. No dye staining was found in non-carious cavity preparations in two studies (Piva & others, 2002; Kidd & others, 1989). However, light dye staining was found in some samples in each of two separate laboratory studies on tooth specimen surfaces created by diamond saw cuts followed by sandpaper grinding (Kazemi, Meiers & Peppers, 2002; Demarco & others, 1998). The latter findings are consistent with the dentin body results of this study.

The variation in staining frequencies and intensities found among sections of the individual tooth specimens could be due to several factors. Since multiple sections were made from each specimen tooth to be used, one per dye, each section would be unique regarding distribution and orientation of the tubules, tubule density and proportion of intertubular versus peritubular dentin in various regions due to the varying anatomic location of each specimen (Mjör, Sveen & Heyeraas, 2001). Patient age and tooth history, both unknown in this study, would have an effect on calcification and dentinogenesis. Although the diamond saw sectioning blade produces a smear layer, it may differ from the smear layer produced during cavity preparation with dental burs. A further study using actual cavity preparations could address the significance of this difference. Finally, variations in technique factors, such as temperature stresses after extraction and the possible effect of mounting stone cutting debris on the section surface, could all affect caries dye staining.

Unique aspects of mantle dentin and pre-dentin may explain differences in dye staining compared to the body of dentin. The mantle dentin adjacent to enamel varies in thickness and contains coarser collagen fibrils arranged differently from that in the main body of dentin (Jones & Boyde, 1984). Mantle dentin may also be less well mineralized (Tronstad, 1972; Herr, Holz & Baume, 1986). The pre-dentin layer is variable in thickness, with thicker areas corresponding to active dentinogenesis (ten Cate, 1988). These factors may provide areas of collagen more susceptible to staining.

CONCLUSIONS

All of the five dyes used produced some degree of staining in each of the 10 non-carious teeth chosen for this study. This staining could be differentiated from the intensity of staining produced by the respective dyes in the carious control teeth, except in two instances. Histologically, no bacteria were found in any area stained with CD dye, except in the control carious lesions. No histologic differences in collagen distribution or morphology were seen in CD dye-stained versus unstained areas. No association was detected between the five dyes and the staining intensity scores for any of the three locations on the specimen sections. The results suggest that these five caries dyes can stain non-carious dentin, but that this staining can be differentiated from the staining of outer carious dentin *in vitro*. Further research is indicated regarding caries dye staining in the area of the dentinoenamel junction and its relationship to traditional indicators of carious dentin such as softness and wetness. To determine clinical implications, research is also indicated on caries dye staining of sound dentin within prepared cavities of carious teeth.

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Comparison of Halogen, Plasma and LED Curing Units

R Nomoto • JF McCabe • S Hirano

Clinical Relevance

Plasma arc and LED units require longer irradiation times than those recommended by their respective manufacturers. Clinicians should be aware of the potential thermal rise and UV-A hazard when using plasma arc units.

SUMMARY

This study evaluated the characteristics of two kinds of recently developed light-curing unit; plasma arc and blue light emitting diodes (LED), in comparison with a conventional tungsten-halogen light-curing unit. The light intensity and spectral distribution of light from these light-curing units, the temperature rise of the bovine enamel surface and the depth of cure of composites exposed to each unit were investigated.

The light intensity and depth of cure were determined according to ISO standards. The spectral distributions of emitted light were measured using a spectro-radiometer. The temperature increase induced by irradiation was measured by using a thermocouple.

Generally, light intensities in the range 400-515 nm emitted from the plasma arc were greater than those from other types. Light in the UV-A region was emitted from some plasma arc units. The required irradiation times were six to nine seconds for the plasma arc units and 40 to 60 seconds for the LED units to create a depth of cure equal to that produced by the tungsten-halogen light with 20 seconds of irradiation. The temperature increased by increasing the irradiation time for every light-curing unit. The temperature increases were 15°C to 60°C for plasma arc units, around 15°C for a conventional halogen unit and under 10°C for LED units.

Both the plasma arc and LED units required longer irradiation times than those recommended by their respective manufacturers. Clinicians should be aware of potential thermal rise and UV-A hazard when using plasma arc units.

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INTRODUCTION

Visible light-cured materials including resin composites, resin modified glass ionomers, cavity liners, fissure sealants, dentin primers, bonding agents and luting agents are widely used in dentistry. The efficiency of the radiation source for photo-polymerization has thus become increasingly important. In daily clinical conditions, the commonly used unit for polymerization of composite materials is a halogen-curing unit. The commonly used halogen light-curing units have some specific drawbacks, including decrease of the light output

with time. The halogen bulb, reflector and filter deteriorate over time due to the high operating temperatures and significant quantity of heat produced during the operating cycle. This results in a reduction of curing effectiveness of the halogen light-curing unit over time. The reduction of light intensity due to long usage of the light-curing unit is reported and well known. In fact, light intensity decreases with time even within a short irradiation period (Nomoto & others, 1998). This may result in a lower degree of monomer conversion for the material, and consequent negative clinical implications.

Developments in light-curing technology have led to the introduction of a plasma-arc light-curing unit and a blue superbright light-emitting diode (LED) unit. Plasma arc light units that deliver high light intensity output for faster curing have been introduced with the claim of relatively short curing times. The development of LEDs operating at 470 nm wavelength also comes as an alternative to standard halogen curing units, and these two types of light-curing unit have recently become commercially available.

A number of studies have addressed the application of blue LED or plasma arc technologies to cure dental materials (Hansen & Asmussen, 1993; Shortall, Harrington & Wilson, 1995; Miyazaki & others, 1998; Fano & others, 2002; Peutzfeldt, Sahafi & Asmussen, 2000; Hofmann & others, 2000; Oesterle, Newman & Shellhart, 2001). There are some reports regarding the light intensities of these light-curing units (Hansen & Asmussen, 1993; Shortall & others, 1995; Miyazaki & others, 1998; Fano & others, 2002) or measuring the depths of cure or mechanical properties of cured composites exposed to these light-curing units (Peutzfeldt & others, 2000; Hofmann & others, 2000; Oesterle & others, 2001). However, these light intensities were measured using various types of commercial dental radiometers and no study has reported the light intensities measured using a radiometer conforming to ISO standards (ISO TS10650, 1999). Dental radiometers cannot accurately evaluate light intensity, because sensitivity to intensity varies with the wavelength and emissions from tungsten-halogen and xenon bulbs of light-curing units have different spectral distributions. The measured irradiance of light-curing units therefore depends on the radiometer used, and it appears that there is little consistency in the irradiance measured with radiometers used in dental practice (Hansen & Asmussen, 1993; Shortall & others, 1995; Miyazaki & others, 1998; Fano & others, 2002).

This study evaluated the characteristics of two types of newly-developed light-curing units. The light intensity and light spectral distributions of these light-curing units, the increase in temperature at the bovine enamel surface and the depth of cure of composites exposed to these light-curing units were investigated.

METHODS AND MATERIALS

Three kinds of light-curing units; tungsten-halogen, plasma arc and LED, were tested. These units are listed in Table 1, together with details of the diameters of light guide tips used and the recording times for light intensity. Apollo 95E, Apollo 95E Elite and Flipo units have two light guide tips that use different filters. A conventional halogen-curing unit, New Light VL II, abbreviated as Halogen, was used as control.

Light Intensity of Each Light-curing Unit

The measurement of light intensity was carried out in accordance with ISO TS10650 (1999). The light intensity was measured using a radiometer (PM500D-2, Molectron Detector Inc, Oregon, USA) with a detector (PM-3, Molectron Detector Inc, OR, USA) and four kinds of optical filters, quartz, Schott GG 385, Schott

Table 1: *Light-curing Units Evaluated*

	Light-curing Unit		Manufacturer	Serial #	Diameter of Light Tip (mm)	Reading Time Light Intensity (s)
Halogen	New Light-VL II	Halogen	GC[1]	21567	12	20
	Apollo 95E	Apollo430	DMD[2]	NE903219	7.2	3
		Elite430			7.2	3
	Apollo 95E Elite	Elite470	DMD	NE909036	7.2	3
Plasma	ARC Light IIM	ARC	Air Techniques[3]	1000	7.3	20
	Credi II	Credi	3M ESPE[4]	00219	8.4	10
	Flipo	Flipo430	GC	P 03G01983	7.2	3
		Flipo470			7.1	3
LED	Elipar Free Light	Elipar	3M ESPE	93980 10000352	7.6	20
	LUXOMAX	LXO	AKEDA dental[5]	20020369	7.7	10

1) GC Co, Tokyo, Japan

2) Dental/Medical Diagnostics, CA, USA

3) Air Techniques, Inc, NY, USA

4) 3M ESPE, MN, USA

5) AKEDA Dental A/S, Lystrup, Denmark

GG 400 and Schott OG 515 (Schott Nippon KK, Tokyo, Japan). It was expressed as a radiant exitance. One of the filters was placed on the detector of the radiometer and light tip, with the radiometer being set so that the detector of the radiometer was parallel to and in contact with the center of the light tip. Then, the value of light intensity through the filter was recorded at a specific time during irradiation as shown in Table 1. The light intensities of the LED type light-curing units were measured at full charge. Plasma arc and halogen units were operated only at 100% of the voltage indicated by the manufacturer, although measurements of light intensity were also performed at 90% and 110% of the recommended voltage. Credi and Flipo units have a continuous mode in which the reading time is 20 seconds after beginning radiation. Light intensities in the 190-385 nm (A) and 400-515 nm wavelength regions (B) and the wavelength region above 515 nm (C) were calculated using the following equations:

Table 2: *Resin Composites Used*

Composite	Manufacturer	Shade	Code	Lot #
Clearfil AP-X	Kuraray Medical Inc[1]	A2	APX-A2	00578A
		C4	APX-C4	00310D
Z100	3M ESPE[2]	A2	Z100-A2	0XG
		C4	Z100-C4	0BU
Z250	3M ESPE	A2	Z250-A2	1KEJ
		C4	Z250-C4	0AK

[1] Kuraray Medical Inc, Kurashiki, Japan
[2] 3M ESPE, St Paul, MN, USA

$$A=(a-b)/D$$

$$B=(c-d)/D$$

$$C=d/D$$

where a is the measured intensity when using a quartz filter, b is the measured intensity when using a Schott GG 385 filter, c is the measured intensity when using a Schott GG 400 filter, d is the measured intensity when using a Shott OG 515 filter and D is the optical cross-sectional area of the light guide tip.

Light Emitted Spectrum

The light emitted spectrum from each light-curing unit was measured using a spectro-radiometer (USR-40D, Ushio Inc, Tokyo, Japan) in the wavelength region from 200 nm to 800 nm.

Depth of Cure for Composite Materials

Three kinds of commercially available visible light-cured composite were used and are listed in Table 2. The curing depth of composites was determined with a scraping method according to ISO 4049 (ISO 4049, 2000). Stainless steel split molds with a cylindrical cavity 4 mm in diameter and 8 mm in depth were used. The composite was placed into the mold to slight excess. A polyester strip was then placed on the mold and the material compressed using a glass plate. The composites were exposed to LED light for 20, 40 or 60 seconds, to the plasma arc for 3, 6 or 9 seconds or to the tungsten-halogen light for 20 seconds. Samples were stored at 23°C in the dark. At 180 seconds after completion of exposure, the composite was carefully removed from the mold and uncured material was gently removed with a plastic spatula. The height of the cylinder of cured material was measured with a micrometer and this value was divided by two. Three determinations were made for each material, curing unit and irradiation time combination. The effect of irradiation time on the depth of cure was investigated for each material using the shade for which the depth of cure was lowest, using the tungsten-halogen curing unit.

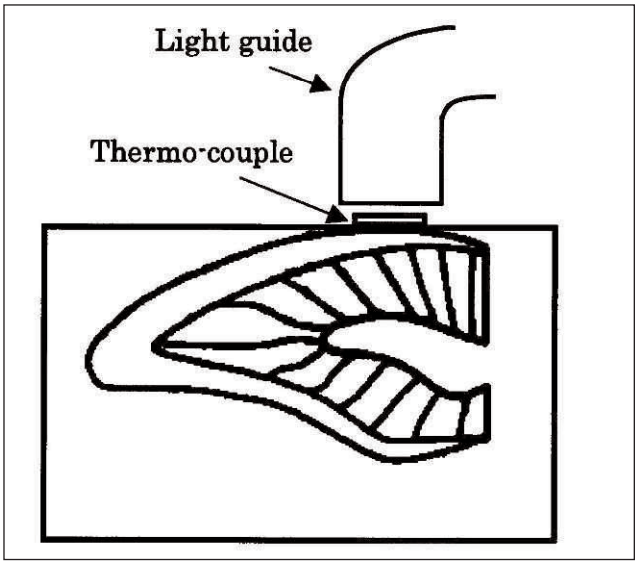

Figure 1. *Schematic diagram of the apparatus for measuring temperature rise of enamel surface.*

Temperature Increase Induced by Irradiation

The enamel surface temperature rise during irradiation was measured using a K-type thermocouple. This is schematically shown in Figure 1. A freshly extracted bovine incisor was embedded in polymethylmethacrylate resin and the labial surface ground to expose a flat area of enamel suitable to support the thermocouple. The temperature on the enamel surface was recorded as a function of irradiation time.

RESULTS

Light Intensity of Each Light-curing Unit

The measured radiance for each light-curing unit is shown in Table 3. Generally, the light intensities in the 400-515 nm band emitted from plasma arc units were greater than those from other types of light-curing units. In the wavelength region of 400-515 nm, the plasma arc units produced irradiances of up to four times that of a halogen unit and up to 10 times that of an LED unit. For the continuous mode of plasma arc units, the light intensity in the 400-515 nm region was only 1/3-1/2 the value measured in the normal mode. For the plasma arc curing units not employing a 470 nm filter, light intensities in the 190-385 nm range were higher than those of other units and exceeded the limit of the current draft ISO standard for powered polymerization activators set at 100 mW/cm^2. In the wavelength region above 515 nm, the conventional halogen unit and some plasma arc units produced higher light intensities as compared with LED units.

Table 3: *Light Intensity of Each Light-curing Unit Measured According to ISO TS10650*

Light-curing Unit	Light Intensity (mW/cm^2)		
	<385 nm	400-515 nm	515 nm<
Halogen	29	377	22
Apollo430	324	1547	29
Elite430	199	1175	23
Elite470	51	1027	10
ARC	124	1714	16
Credi	101	1542	
11*	511	5*	
Flipo430	292	793	0
	155*	401*	2*
Flipo470	3	1293	5
	62*	697*	3*
Elipar	7	179	4
LXO	5	98	4

**: continuous mode*

Table 4: *Results of Depth of Cure (mm) Measured According to ISO 4049*

Light-curing Unit	Irradiation Time(s)	Resin Composite					
		APX-A2	APX-C4	Z100-A2	Z100-C4	Z250AZ	Z250-C4
Halogen	20	2.23(0.03)	1.61(0.03)	2.57(0.03)	2.51(0.07)	2.39(0.07)	2.49(0.04)
Apollo430	3	1.64(0.13)	1.11(0.06)	2.02(0.07)	1.96(0.03)	1.84(0.05)	1.93(0.05)
	6	-	1.36(0.05)	-	2.36(0.05)	2.07(0.03)	-
	9	-	1.62(0.04)	-	2.59(0.06)	2.26(0.04)	-
Elite430	3	1.48(0.05)	1.11(0.01)	1.87(0.01)	1.81(0.04)	1.76(0.05)	1.88(0.02)
	6	-	1.27(0.08)	-	2.27(0.02)	2.07(0.01)	-
	9	-	1.45(0.05)	-	2.49(0.03)	2.30(0.03)	-
Elite470	3	1.93(0.05)	1.38(0.10)	2.15(0.03)	2.13(0.06)	2.45(0.05)	2.30(0.06)
	6	-	1.67(0.10)	-	2.66(0.01)	2.81(0.05)	-
	9	-	1.88(0.08)	-	2.97(0.06)	3.08(0.04)	-
ARC	3	1.77(0.02)	1.28(0.04)	2.20(0.05)	2.15(0.02)	2.36(0.06)	2.30(0.03)
	6	-	1.69(0.02)	-	2.73(0.04)	2.69(0.02)	-
	9	-	1.85(0.02)	-	3.02(0.06)	2.93(0.05)	-
Credi	3	1.65(0.08)	1.24(0.05)	1.88(0.07)	1.90(0.07)	2.06(0.05)	1.99(0.07)
	6	-	1.50(0.02)	-	2.37(0.06)	2.47(0.04)	-
	9	-	1.72(0.07)	-	2.75(0.02)	2.74(0.06)	-
Flipo430	3	1.55(0.11)	1.20(0.00)	1.75(0.03)	1.61(0.03)	1.56(0.02)	1.64(0.04)
	6	-	1.28(0.07)	-	1.95(0.03)	1.88(0.02)	-
	9	-	1.48(0.13)	-	2.23(0.03)	2.04(0.04)	-
Flipo470	3	2.04(0.08)	1.57(0.08)	2.29(0.05)	2.30(0.03)	2.53(0.08)	2.41(0.01)
	6	-	1.84(0.02)	-	2.80(0.03)	2.90(0.04)	-
	9	-	2.12(0.13)	-	3.14(0.03)	3.15(0.08)	-
Epilar	20	2.08(0.06)	1.57(0.03)	2.39(0.03)	2.43(0.05)	2.46(0.06)	2.30(0.03)
	40	2.52(0.03)	1.88(0.01)	2.82(0.02)	2.90(0.05)	2.79(0.04)	
	60	2.80(0.01)	2.07(0.07)	3.01(0.02)	3.13(0.05)	3.02(0.00	-
LXO	20	1.73(0.12)	1.16(0.05)	1.80(0.08)	1.79(0.01)	1.88(0.03)	-
	40	1.88(0.03)	1.38(0.01)	2.25(0.04)	2.24(0.05)	2.21(0.03)	2.23(0.02)
	60	2.20(0.06)	1.58(0.03)	2.47(0.04)	2.50(0.02)	2.47(0.02)	-

Numbers in parenthesis are standard deviations

The Light Spectrum Emitted from Light-curing Unit

The spectrum produced by each light-curing unit is shown in Figure 2. The halogen light-curing unit showed a broad distribution of wavelengths from 400 nm to 500 nm, with a power peak at 497 nm. The spectrum from one of the plasma arc units, ARC, had a broad spectral distribution of irradiance with a peak at 470 nm and a long tail to shorter wavelengths. The spectra of the plasma arc units with a 430 nm filter were within the range from 375 nm to 475 nm, while the plasma arc units with a 470 nm filter emitted light within the most effective region for excitation of camphorquinone, 450-490 nm. The light emitted from LED units was confined to the most effective region for activation. Light in the UV-A region was emitted from Apollo430, Elite430, Flipo430 and ARC units.

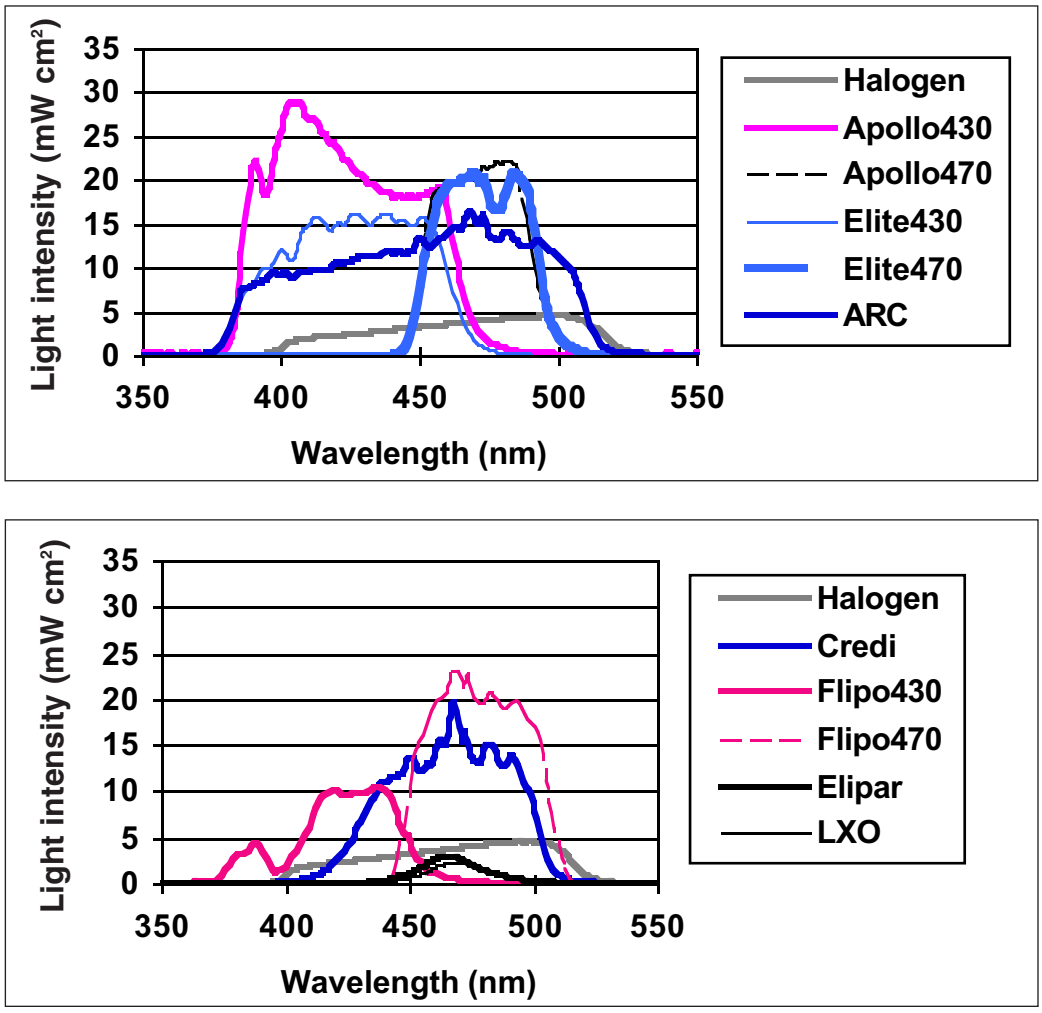

Figure 2. *Spectra emitted from each light-curing unit.*

Depth of Cure for Composite Materials

Table 4 shows the depths of cure of the resin composites. The depth of cure of composites exposed to halogen units for 20 seconds was more than 1.5 mm in all cases and, in this respect, the materials satisfy one requirement of ISO 4049 (ISO 4049, 2000). The depth of cure with the plasma arc units for three seconds of exposure, which was recommended by the

Table 5: *Temperature (°C) Rise Induced During Irradiation*

Light-curing Unit	Mode	Irradiation Time(s) 3	6	9	10	20	30	40
Halogen		-	-	-	11.7	13.9	15.2	15.9
Apollo430		52.0	55.0	58.1	-	-	-	-
Apollo470		25.1	28.7	29.1	-	-	-	-
Elite430		25.5	29.8	33.4	-	-	-	-
Elite470		16.9	17.5	19.9	-	-	-	-
ARC		32.6	35.7	37.2	-	-	-	-
Credi		15.7	21.6	25.4	-	-	-	-
	continuous mode	-	-	-	8.4	-	-	-
Flipo430		16.8	20.2	21.9	-	-	-	-
	continuous mode	-	-	-	10.4	12.4	-	-
Flipo470		18.4	20.3	21.0	-	-	-	-
	continuous mode	-	-	-	12.3	14.9	-	-
Elipar		-	-	-	3.8	4.5	5.0	5.4
LXO		-	-	-	1.7	1.9	2.0	2.2

manufacturer of the units, was less than that obtained with the conventional tungsten-halogen unit, with 20 seconds of exposure. Six to nine seconds of exposure was typically required for the plasma arc units and 40 to 60 seconds for the LED units to give a depth of cure equal to that produced by the tungsten-halogen light. The depth of cure obtained using the plasma arc with a 430-nm filter was less than that obtained with a 470-nm filter.

Temperature Increase of Bovine Enamel During Irradiation

Table 5 shows the temperature increase of bovine enamel during irradiation by each unit. The higher the light intensity of light-curing unit, the higher the rise in temperature of the exposed surface. The plasma arc light units caused a much higher temperature rise due to irradiation as compared to the conventional halogen light-curing unit. The temperature increased with increasing the irradiation time for every light-curing unit. The temperature increases were 15°C to 60°C for plasma arc units, around 15°C for conventional halogen unit and under 10°C for LED units.

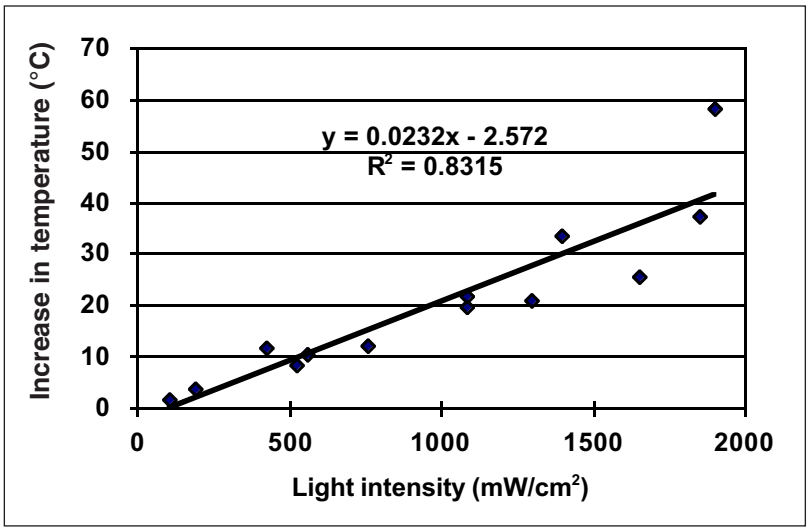

Figure 3. *Relationship between temperature rise and light intensity.*

The relationship between the temperature rise and light intensity was investigated and shown in Figure 3. The data of the temperature rise at nine or 10 seconds exposure was used. The amount of the values of light intensity in the 190-385 nm and 400-515 nm wavelength regions and the wavelength region above 515 nm was used as the light intensity. The temperature rise and the light intensity bear a linear relationship to each other.

DISCUSSION

Ultraviolet radiation (below 385 nm) and illumination above 500 nm that could cause pulpal damage should be eliminated from radiation produced in dental curing unit lamps. For tungsten-halogen and plasma arc curing units, these unwanted wavelengths are thus removed by filters placed between the light source and light guide. In the current ISO standard (ISO TS10650, 1999), light intensities of three wavelength regions, 190-385 nm, 400-515 nm and above 515 nm are measured using four different kinds of filters.

The peak of the absorption spectrum of the photo-initiator, camphorquinone, used in light cured dental materials is within the wavelength region from 400 to 500 nm (Nomoto, 1997). The most effective wavelength to activate polymerization of these materials is 470 nm, and the most effective wavelength band is in the range 450-490 nm (Nomoto, 1997). The spectral output of LED units falls conveniently within this most effective wavelength range, so that no filters are required for LED units. LEDs, therefore, have the potential to activate the polymerization of dental composites used in this study without the drawbacks associated with other types of light-curing units.

When measuring light intensity using the method outlined in the current ISO standard (ISO TS10650, 1999), the recording time should be 20 seconds after starting irradiation, but most of the plasma arc units and some of the LED units could not be used continuously for such a long time, and for these units, the measurement was made at the longest possible time.

According to the current ISO standard (ISO TS10650, 1999), the upper limit of light intensity in the 190-385 nm range is 100 mW/cm^2 and the upper permissible limit above 515 nm is 50 mW/cm^2. The acceptable range of light intensity in the 400-515 nm wavelength region is 300-1000 mW/cm^2. These limit values are standardized for light-curing units of the tungsten-halogen type and not for plasma arc or LED units. However, it is interesting to evaluate the newer units against the same standard limits. Above 515 nm, the light intensity of each light-curing unit was below the maximum allowed limit value of the ISO standard (ISO TS10650, 1999). The light intensity in the 190-385 nm wavelength region for the Apollo430, Elite430, Flipo430 and ARC units exceeded the limit value of the current ISO standard. With regard to the 400-515 nm wavelength region, the light intensity of most of the plasma arc and LED units was outside the acceptable range for halogen units. For the plasma arc units, light intensities in this wavelength range were more than 1000 mW/cm^2, while for the LED units, light intensities in the range were less than 300 mW/cm^2.

The ultraviolet hazard standard published by the American Conference of Governmental Industrial Hygienists (ACGIH) identifies the threshold light value to which a person can be safely exposed every working day. Ultraviolet is divided into three wavelength bands:

UV-A (400-315 nm), UV-B (315-280) and UV-C (280-100) according to its effects on living tissue. The UV region associated with dental light-curing units is UV-A. The current exposure limit specified for UV-A exposure of the unprotected eye is 1 mW/cm^2 within any 1000-second period in one day. UV-A radiation was emitted from some plasma arc units between 360 and 400 nm, and even some LED and conventional halogen units emitted small amounts of UV-A. Therefore, dentists and patients should wear protective spectacles. Alternately, patients should be advised to close their eyes during the use of all light curing units.

Two shades of each product were selected, since depth of cure depends on the color and translucency of the material (McCabe & Carrick, 1989). The effect of irradiation time on the depth of cure was investigated using the shade for which the depth of cure was lowest using the tungsten-halogen-curing unit. The minimum depth of cure specified in the ISO standard for resin-based filling materials (ISO 4049, 2000) is 1.5 mm. The depth of cure of the six composites exposed to the conventional tungsten-halogen light clearly satisfied this depth of cure requirement (ISO 4049, 2000). Although light intensities in the 400-515 nm wavelength regions for LED units were less than the minimum value of 300 mW/cm^2 specified in the ISO standard, the depth of cure of composites exposed to LED units for 20 seconds was in excess of 1.5 mm, with the exception of APX-C4 exposed to the LXO lamp.

A linear relationship exists between the depth of cure and the logarithm of total exposure, that is, the product of the light intensity and the irradiation time (Cook, 1980; Cook, 1986; Nomoto, Uchida & Hirasawa, 1994). To obtain the same equivalent exposure for 20 seconds using a Halogen unit, the required irradiation times were calculated as 4.8 seconds for Apollo430, 6.4 seconds for Elite430, 7.3 seconds for Elite470, 4.4 seconds for ARC, 4.9 seconds for Credi, 9.5 seconds for Flipo430, 5.8 seconds for Flipo470, 42 seconds for Elipar and 77 seconds for LXO. In fact, the required irradiation time for APX-C4 was 9 seconds for Apollo430, more than 9 seconds for Elite430, 6 seconds for Elite470, 6 seconds for ARC, 9 seconds for Credi, more than 9 seconds for Flipo430, 3 seconds for Flipo470, 20 seconds for Elipar and 60 seconds for LXO; whereas, the required irradiation time for Z100-C4 was 9 seconds for Apollo430, 9 seconds for Elite430, 6 seconds for Elite470, 6 seconds for ARC, 9 seconds for Credi, more than 9 seconds for Flipo430, 6 seconds for Flipo470, 20 seconds for Elipar and 60 seconds for LXO. The required irradiation time for Z250-A2 was more than 9 seconds for Apollo430, more than 9 seconds for Elite430, 3 seconds for Elite470, 3 seconds for ARC, 6 seconds for Credi, more than 9 seconds for Flipo430, 3 seconds for Flipo470, 20 seconds for Elipar and 60 seconds for LXO. To obtain a depth of cure comparable to that achieved by Halogen units for 20 seconds of irradiation, the required irradiation times were generally shorter for plasma units employing a 470-nm filter and LED units than the calculated values. This may be due to the spectral distribution of the light-curing units since light emitted from the Halogen unit covered a wide region, ranging from 400-500 nm. However, light emitted from plasma arc units with a 470-nm filter and LED units were concentrated within the most effective region for activation of polymerization, 450-490 nm. Despite the relatively low irradiance of LEDs, their curing efficacy was close to that of a conventional halogen light-curing unit with more than twice the irradiance. For plasma units with a 430 nm filter, the required irradiation time to obtain a depth of cure comparable to that achieved with the Halogen unit at 20 seconds of irradiation was at least 9 seconds. This may have been due to the fact that much of the light emitted from these units lies outside the effective region of 450-490 nm.

Many studies have reported the extent of temperature rise during irradiation through dentin, veneer or resin restorative (Smail & others, 1988; Tjan & Dunn, 1988; Shortall & Harrington, 1998; Hannig & Bott, 1999; Loney & Price, 2001; Knezevic & others, 2001). When there is a restoration in the approximal surface and cervical region, a mucous membrane may be directly exposed to the emitted light from a light-curing unit. The high temperature increase induced might cause damage to adjacent soft tissues. The degree of moisture on enamel surfaces may affect the temperature increase induced during irradiation, so the experimental enamel used in this study was kept in a desiccator with silica gel. According to Zach and Cohen (1965), a temperature increase in the pulp of 5.5°C or more may cause pulpal damage. When bonding agents are cured by a light-curing unit, sufficient heat may be generated to cause pulpal damage. When restorative materials are cured, a measure of protection from the light can be anticipated due to the thickness and specific heat of restorative material. The light intensity, exposure time and temperature elevation of the exposed tooth are closely related, and potentially damaging temperatures can be reached. Clinicians should be aware of the potential thermal hazard not only to the pulp, but also to soft tissues.

CONCLUSIONS

Plasma arc curing units make it possible to polymerize resin composites using much shorter radiation times than conventional halogen curing units. Although the depths of cure of composites exposed to plasma units for three seconds or LED units for 20 seconds have satisfied the minimum depth of cure requirement of 1.5 mm outlined in the ISO standard (ISO 4049, 2000) (with the exception of APX-C4 exposed to LXO for 20 seconds), these units require longer irradiation times than those

recommended by their respective manufacturers to create a depth of cure equal to that produced by the tungsten-halogen light for 20 seconds of irradiation. Clinicians should be aware of the greater potential thermal and UV-A hazard when using plasma arc units when compared with other types of light activation curing devices.

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Effect of Fractured or Sectioned Fragments on the Fracture Strength of Different Reattachment Techniques

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Clinical Relevance

The way fragments are obtained in laboratory tests plays an important role in the fracture strength recovery of the reattachment techniques tested. When the fragments are fractured, the over-contour and internal groove techniques seemed to be excellent choices.

SUMMARY

This study evaluated the effect of fractured or sectioned fragments on the fracture strength recovery of four techniques used for reattachment and resin composite buildups. Ninety-one sound, permanent lower central incisors were used. Half the teeth were fractured in the incisal-proximal edge; the other half had the incisal-proximal edge sectioned by a diamond saw. Teeth from each half were randomly divided into five techniques: 1) bonded only; 2) chamfer; 3) over-contour; 4) internal dentinal groove and 5) resin composite buildup. An adhesive system and dual cure resin cement were employed for the reattachment. Restored teeth were subjected to load in a specific point on the buccal surface. Based on the fracture strength of sound teeth, a fracture strength recovery was calculated for each tooth. A one-way ANOVA and Tukey's test (α=0.05) were used to evaluate differences between the techniques for each method of obtaining fragments. The fracture strength recovery of similar techniques was evaluated by a *Student t*-test (α=0.05). No differences could be detected among reattachment techniques when fragments were obtained by sectioning. In groups where the fragments were fractured, Techniques 3 and 4 showed the highest fracture strength recovery. The resin composite buildup provided fracture strength recovery similar to intact teeth regardless the way fragments were obtained.

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INTRODUCTION

The reattachment of fragment after a tooth trauma has several advantages over conventional Class IV resin composite restorations (Baratieri & others, 1994; Busato

& others, 1998). However, there are still doubts about the fracture strength and longevity of several reattachment techniques employed by clinicians.

Many techniques have been proposed to reattach the fragment to the remaining tooth: use of a circumferential bevel before reattaching (Simonsen, 1979; Amir, Bar-Gil & Sarnat, 1986; Walker, 1996), placement of a chamfer at the fracture line after bonding (Davis, Roth & Levi, 1983; Andreasen & others, 1995), use of a V-shaped enamel notch (Simonsen, 1982), placement of an internal dentinal groove (Walker, 1996; Baratieri & others, 1994) or placement of a superficial over-contour over the fracture line (Reis & others, 2001). Some authors also indicate bonding of the fragment without any additional preparation (Osborne & Lambert, 1985; Martens & others, 1988).

Reis and others (2001) have evaluated different reattachment techniques and concluded that placement of a superficial over-contour over the fracture line, as well as placement of an internal groove in the fragment and remnant, provided fracture strength as high as that of sound teeth. However, other experimental designs have not shown any statistical difference among the fracture strengths of two or more techniques (Munksgaard & others, 1991; Worthington, Murchison & Vandewalle, 1999).

This controversy makes the technique choice difficult for clinicians and requires further studies. It is likely that different methodologies employed in laboratory tests play an important role in the results of reattachment techniques. It was already demonstrated that the speed of the applied force necessary to cause the trauma interferes with the results obtained (Andreasen & others, 1993; Farik & Munsksgaard, 1999) and the load distance from the plane of fracture (De Santis & others, 2001). Another source of variation, not yet addressed, is the origin of the teeth employed among published studies. Bovine (Badami, Dunne & Scheer, 1995; Worthington & others, 1999; De Santis & others, 2001; Munksgaard & others, 1991; Andreasen & others, 1993; Farik & others, 1998a,b) and human teeth have been employed in independent experimental studies (Dean, Avery & Swartz, 1986; Pagliarini & others, 2000; Reis & others, 2001, 2002).

Among other variables, the method researchers employ to obtain fragments for testing seems to be relevant. Four studies that reported controversial results regarding the performance of techniques used for reattachment (Munksgaard & others, 1991; Worthington & others, 1999; Reis & others, 2001, 2002) employed distinct methodologies to obtain their fragments. While Reis and others (2001, 2002) fractured teeth in a universal machine, Worthington and others (1999) sectioned the incisal edge of teeth. Both methods were also used in other experimental setups (Pagliarini & others, 2000; Dean & others, 1986; Farik & others, 1998a,b; De Santis & others, 2001). Therefore, this study evaluated the effect of fractured or sectioned fragments on the fracture strength recovery of four techniques used for reattachment and resin composite buildups.

METHODS AND MATERIALS

Ninety-one sound, human lower incisors extracted due to periodontal disease were selected under optical magnification (2x). Only teeth free from cracks or any other kind of structural defect were selected. The teeth were disinfected in 0.5% chloramine for 15 days and stored for less than six months in 0.9% saline solution. The test consisted basically of three procedures: 1) method of obtaining fragments; 2) restoration of the fractured teeth and 3) fracture of the restored teeth.

1. Method of Obtaining Fragments

The buccal surface of each tooth was divided into transversal and longitudinal thirds according to Reis and others (2001, 2002). Then, 51 teeth were fractured as described below (Item 1.1), while the other 40 teeth were sectioned as described in Item 1.2. A Class II Ellis fracture type was to be obtained (Ellis & Davey, 1970).

1.1 Fracture of the Sound Teeth

This methodology was used elsewhere (Reis & others, 2001, 2002). The area (point) for application of the perpendicular loading was placed between the superior and proximal (mesial or distal) thirds as shown in Figure 1A. The roots of the teeth were confined in a special device (holder) and adapted in a universal testing machine (EMIC Testing Machine, São José dos Pinhais, PR, Brazil). The load was applied to each tooth in a buccal to lingual direction by means of a small, stainless steel ball (2 mm^2) inserted at the end of a pin held in the crosshead of the universal testing machine at a speed of 1.0 mm/minute. The force required to fracture the teeth was recorded. Only teeth that had a perfect fit after fracture were used (n=40).

1.2 Sectioning of the Sound Teeth

The teeth were positioned in a Labcut 1010 laboratory saw (Extec Corp, Enfield, CT, USA) and a 0.15 mm water-cooled diamond saw set at 200 rpm sectioned the mesial or distal edge of each tooth. The sectioning was performed from the proximal to the incisal edge, having the region described in the Item 1.1 as a reference for the diamond saw (Figure 1B).

2. Restoration of the Fractured Teeth

All teeth were kept in 0.9% saline solution until performing the restoration procedure (Farik & others, 1998b). The materials used were a one-bottle adhesive system (Excite, Vivadent, Schaan/Liechtenstein, Germany, batch #C33179), a dual cure resin cement (Variolink, Vivadent, Schaan/Liechtenstein, Germany, batch number – A23654 and A23650) and a resin com-

posite (Tetric Ceram, Vivadent, Schaan/Liechtenstein, Germany, batch #903309) applied following the manufacturer's instructions. Table 1 shows the techniques used. Eight teeth were used for each experimental condition.

Teeth from Techniques 1, 2 and 3 had their fragments reattached using a resin luting cement (Variolink, Vivadent). The adhesive system (Excite, Vivadent) was applied to both the fragment and the remnant. However, the adhesive was not immediately light cured in order to avoid any interference with the fit between the parts to be bonded. After that, the resin cement was applied, the fragment reattached and the buccal and lingual surfaces light cured for 40 seconds each.

In Technique 1, no additional preparation was made. In Technique 2, after reattachment, a 1.0-mm depth chamfer was placed in the fracture line in the buccal surface using a diamond round bur (ref #1016, KG Sorensen, São Paulo, Brazil) (Table 1). In teeth from Technique 3, a preparation was placed in the buccal surface by means of a cylindrical diamond finishing bur (ref #2135F. KG Sorensen) extending 2.5 mm coronally and apically from the fracture line with a depth of 0.3 mm (Table 1). One increment of resin composite (shade A2 dentin – Tetric Ceram, Vivadent) was used in Techniques 2 and 3 to restore the buccal surface after applying the adhesive system (Excite, Vivadent). This created a slightly over-contoured tooth surface.

In Technique 4 prior to performing the reattachment technique, an internal groove (1-mm deep and 1-mm wide) was placed within the fragment and the remaining tooth by means of a carbide bur (ref #329, KG Sorensen) with a water-cooled, high-speed handpiece (Table 1). The Excite adhesive system (Vivadent) was applied to each surface. Prior to light curing, a resin composite (Tetric Ceram, Vivadent) was placed within the groove. The fragment was reattached and the excess composite removed. Each surface was then light cured for 40 seconds.

No re-attachment technique was used in the fractured teeth from Technique 5 (Table 1). A 45° bevel extending 1 mm on the buccal surface was prepared using a cylindrical diamond finishing bur (ref #2135F, KG Sorensen) and a resin composite buildup (Tetric Ceram, Vivadent) was performed after adhesive application (Excite, Vivadent) (Table 1). The restorations were made following the incremental technique (approximately 2-3 increments). Each increment was light cured for 40 seconds.

For polymerization purposes, a light-curing unit VIP (BISCO Inc, Itasca, IL, USA) with a light output of 600 mW/cm^2 was used. The teeth were finished and polished with flexible discs (Sof-Lex Pop On polishing discs, 3M ESPE, St Paul, MN, USA) 24 hours after the restorative procedure.

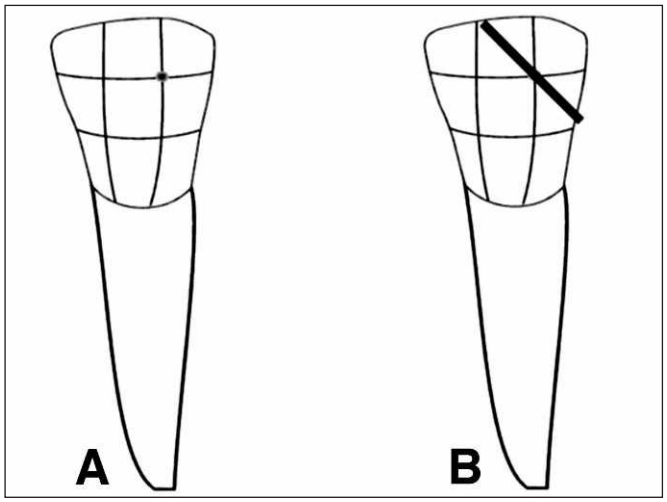

Figure 1. *A: Standardized area for load application to cause the fracture of the teeth. 1B: Direction of the diamond saw used for sectioning the proximal edge of the teeth.*

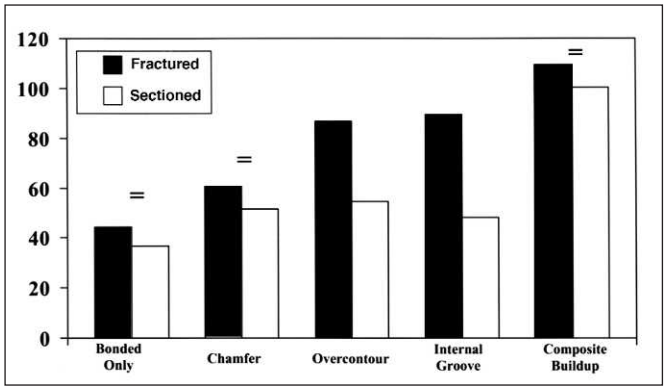

Figure 2. *Fracture strength recovery (%) of the experimental groups.*

Table 1: *Technique, Description and Sequence of the Materials*

Technique	Description	Sequence of the Materials
1 Bonded only	Reattachment of the fragment with no additional preparation	Adhesive system + resin cement
2 Chamfer	Reattachment of the fragment + chamfer in the buccal surface	Adhesive system + resin cement + resin composite
3 Overcontour	Reattachment of the fragment + superficial preparation on the enamel	Adhesive system + resin cement + resin composite
4 Internal groove	Internal dentinal groove + reattachment of the fragment	Adhesive system + resin cement + resin composite
5 Composite buildup	No fragment was used	Adhesive system + resin composite

3. Fracture of the Restored Teeth and Data Analysis

The specimens were loaded in the same pre-determined area used in Procedure 1.1 until failure. The force required to detach each fragment was recorded in Kgf. The fracture strength of all sound teeth was averaged. For each tooth, the fracture strength was expressed as a percentage of the load required to fracture the sound tooth (strength recovery). This allowed for establishing a relationship between the fracture strength of an intact tooth and that obtained after restorative procedures for all groups.

A one-way ANOVA and Tukey's test (α=0.05) were used to evaluate differences among the techniques for each method of obtaining fragment. A comparison of the fracture strength recovery of similar techniques under the different methodologies was evaluated by a *Student t-test* (α=0.05).

RESULTS

The mean force (standard deviation) required to fracture sound teeth was 22.12 ± 4.1 Kgf. Table 2 presents the mean fracture resistance (Kgf) and standard deviation of sound and restored teeth and the strength recovery (%) of each group.

No difference was detected among the techniques (p>0.05) except for resin composite build-up when the fragments were sectioned (Figure 2). However, when the fragments were fractured, performance of the groups was different (Figure 2). Techniques 1 (bonded only) and 2 (buccal chamfer) showed similar fracture strength recovery (p>0.05); however, these values were lower than those obtained with Techniques 3 (over contour), 4 (internal groove) and 5 (composite resin build-up) (p<0.05).

The comparison between similar techniques under different methodologies showed that Groups 1, 2 and 5 had statistically similar results (p<0.05) (Figure 2). Techniques 3 and 4 performed differently, depending on the methodology employed. Higher fracture strength recovery was observed when the fragments were fractured (p<0.05). The fracture path of the restored teeth followed the bonded interface in all specimens.

Table 2: *Mean Fracture Strength (Kgf) and Standard Deviations of Sound*

	Fracture			Sectioning		
Reattachment Techniques	**Mean**	**± SD**	**% (*)**	**Mean**	**± SD**	**% (*)**
1 Bonded only	9.8	3.7	44.3	8.2	1.4	36.9
2 Chamfer	13.4	4.8	60.6	11.4	1.9	51.5
3 Overcontour	19.2	3.4	86.8	12.1	3.3	54.7
4 Internal groove	19.8	2.2	89.5	10.6	4.4	47.9
5 Composite buildup	24.2	7.8	109.4	22.2	3.5	100.4

(*) Fracture strength recovery was calculated based on the mean and standard deviation of the fracture strength of sound teeth (22.12±4.1)

DISCUSSION

The authors have already employed the same experimental design in previous publications (Reis & others, 2001; 2002). The mean force required to cause fracture of sound teeth in these studies showed very similar values. Reis and others (2001) have shown that over-contour and internal groove reattachment techniques had excellent performance compared to the other techniques tested. In groups where the fragments were fractured instead of sectioned, the same results were obtained; that is, superiority of the over-contour and internal groove techniques could be detected.

However, when fragments were obtained by sectioning, all the reattachment techniques had similar performance, with fracture strength recovery ranging from 36.9% to 54.7%. Worthington and others (1999), testing different reattachment techniques (no preparation; circumferential internal bevel; circumferential external bevel; facial internal bevel associated with lingual external bevel), demonstrated that all performed equally. Overlooking the fracture strength recovery range of the above techniques (32.3% to 41.7%), one may conclude that they are similar to those obtained in this investigation when the sectioning procedure was employed. Interestingly, the second part of this study and that of Worthington and others (1999) yielded the same conclusion and obtained fragments in a similar manner by means of sectioning.

These results can demonstrate that micromechanical interlocking between the fragments and the respective remnant is very important for fracture strength recovery of the technique employed. As emphasized by Badami and others (1995), the surface anatomy produced by sectioning is likely different from that produced as a result of fracture. A fractured surface tends to run parallel to the main direction of the enamel prisms, while orientation of the sectioned surface is dictated by alignment of the diamond saw used to section the incisal edge. The fit between the fragment and remaining teeth is lost by sectioning, and strength of the reattached tooth relies only on the bonding of material to the sectioned interfaces and the mechanical properties of the materials employed (Reis & others, 2002).

Although some studies have shown that the association of materials used for reattachment does not increase the fracture strength recovery of bonded teeth (Dean, Minutillo & Moore, 1998; Reis & others, 2002), Reis and others (2002) have demonstrated a trend towards improved fracture strength recovery when fractured parts were bonded with a bonding

agent and a high strength material such as a resin composite.

In this way, one can speculate that fracture methods simulate clinical fractures, where the parts fit together with no discernible disruption. On the other hand, the method of sectioning simulates clinical fractures, with excessive tissue loss and lack of mechanical interlocking between the fractured parts. This means that the techniques employed may be dependent on the fracture pattern and the fit between the fragments and the remnant. Probably, when the parts do not fit together, the fracture strength recovery of that technique would not be higher than 50%, because it would rely only on the material used for reattachment. In these cases, it seems that the association of adhesive systems with high strength materials, such as composites, could lead to higher fracture strength recovery. However, no laboratory and clinical studies have addressed this issue, which requires further evaluations.

The simple reattachment group showed similar results either when the fragments were obtained by fracture or sectioning, with a fracture strength recovery ranging between 36.9% and 44.3%. Munksgaard and others (1991) concluded that reattachments without preparation and with the use of dental bonding agents exhibited about 50% of the fracture strength displayed by intact teeth. Reis and others (2002) also reached similar conclusions. Although other studies have published techniques, that without preparation, were bonded with adhesive systems reaching fracture strength as high as those provided by intact teeth (Farik & others, 1998a,b; Farik, Munksgaard & Andreasen, 2000), the authors of this study do not advise performing this technique until further studies elucidate such controversy.

Undoubtedly, under fractures with a good fit between the parts, the choice of over-contour and/or internal groove technique seem to be the best alternative. These techniques may provide higher fracture strength than the simple reattachment or chamfer groups. The addition of resin composite in a wider area of the external buccal surface (overcontour technique) may better distribute the fracture forces on the whole surface, avoiding stress concentration on the fracture line. On the other hand, placement of an internal bar of resin composite (internal groove) may absorb part of the stresses placed on the buccal surface, thus reinforcing the bonded teeth.

For both methods of obtaining teeth fragments, resin composite build-up could reach fracture strengths as high as those displayed by sound teeth. This technique may be considered only when the fragment is not available, because a good color match is more difficult to perform; it has a higher cost, consumes more chair-time and the wear mechanism is unfavorable since composite wears more than enamel.

Unfortunately, there are no clinical trials in the literature that evaluate reattachment techniques except for a multi-center clinical study by Andreasen and others (1995). The authors have compared the longevity of resin composite buildups and bonded fragment (only bonded) in 20 patients with two coronal fractures each. The mean survival time was 784 ± 528 days (range of 27 to 1.872 days) for the bonded fragment and 701 ± 553 days (range of 28 to 1.864 days) for the buildups. The authors also pointed out that at the end of the study, seven bonded fragments and 14 resin composite buildups were intact. Actually, the low sample size, high standard deviations and inferior performance of the materials used in the study prevent the authors from making conclusive statements. However, comparison of the number of intact restorations at the end of the study seems to show that composite buildups performed better than bonded restorations. It is likely that the lower survival rate of the reattachment is probably due to the lack of additional preparation either prior to or after fragment bonding. Clinical trials should be conducted to confirm the hypothesis presented by laboratory investigations.

CONCLUSIONS

Within the limitations of this study, it was concluded that the way fragments are obtained in laboratory tests plays an important role in fracture strength recovery of the techniques tested. When the fragments are obtained by fractures, the over-contour and internal groove techniques seemed to be excellent choices.

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Influence of Flowable Composite Lining Thickness on Class II Composite Restorations

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Clinical Relevance

In this study, the application of additional flowable composite lining with various thicknesses presented different influences in marginal quality and internal voids of Class II box-only composite restorations. A new technique applying an ultrathin flowable composite lining achieved reduction in both marginal microleakage and internal voids. Restorations with thick, flowable composite linings presented a high opening margin percentage and reduced marginal integrity after the thermocycling test.

SUMMARY

This *in vitro* study aimed to investigate the influence of flowable composite lining with different thicknesses on the marginal quality and internal porosity of Class II composite restorations. Thirty-two intact molars, each prepared with two box-only Class II cavities, were randomly divided into four groups: Group 1, P60 filling alone; Group 2, ultrathin flowable composite lining/co-cured with overlaying composite; Group 3, thin lining/pre-cured and Group 4, thick lining/pre-cured. The teeth were then thermocycled for 1500 cycles (between 5°C and 60°C) and dye immersed for 24 hours. Exterior surface replicas of these restorations were fabricated before and after thermocycling and examined by SEM to evaluate percentages of the five marginal patterns. Data was statistically evaluated using one-way ANOVA test. The teeth were subsequently sectioned longitudinally. The interface microleakage of cervical margin was measured as to the extent of dye penetration. Internal voids were separately recorded in the cervical interface and the cervical and occlusal halves of the restorations. Mann-Whitney test was applied to analyze the interface microleakage and internal voids. Results revealed that replicas of Group 4 presented the highest percentage of marginal openings both before and after thermocycling in SEM examination. Group 2 exhibited superior marginal quality in interface microleakage evaluation compared to the other groups, while Group 4 exhibited the worst. The pre-cured groups (Group 3 and 4) showed significant reduction in interface and cervical voids. Despite the reduction in interface voids, a thick lining may impair the marginal sealing, especially after

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thermocycling. It was concluded that a minimally thin flowable composite lining improved cavity adaptation and marginal sealing.

INTRODUCTION

With the increasing demand for aesthetic dentistry and concerns regarding mercury toxicity, the popularity of posterior composite restoration has increased (Leinfelder, 1995). Current composite restorations have proved to be successful in small Class I and II cavities (Geurtsen & Schoeler, 1997). Advances in filler technology have caused the wear rate of posterior composite restorations to approach that of amalgam restorations (Suzuki & others, 1995). However, difficulty in obtaining intimate cavity adaptation and marginal complete sealing in posterior resin composite restorations may result in postoperative problems, such as sensitivity and adversely affecting the clinical performance of these restorations (Opdam & others, 1998a).

Intimate cavity adaptation can be obtained by forced condensing in dental amalgam restorations. Unfortunately, unlike amalgam, resin composite cannot be easily condensed under a heavy force. Improper insertion and repeated condensing motion will induce internal porosity formation (Opdam & others, 1996). Additionally, the stickiness of resin composite to the instrument makes adaptation of the cavity more difficult. A previous study (Hattab, Mok & Agnew, 1989) demonstrated that improper placement by the clinician resulted in an inadequate seal on the restorative interface and an increased likelihood of caries formation. Recently, a new category of resin composites called "packable" or "condensable composites" was introduced to provide improved handling properties. By changing the filler phase or matrix system, the viscosity of these materials was increased to resist a greater condensing force (Cobb & others, 2000). Using this category of resin is widely believed to help obtain a good cavity adaptation. However, most recent studies did not establish the superiority of condensable composites over conventional hybrid composites either in terms of resistance to condensing force or microleakage prevention (Brackett & Covey, 2000; Neme & others, 2002).

Complete marginal sealing is also difficult to achieve, especially in the cervical margins of Class II composite restorations (Dietschi & others, 1995). A previous study (Opdam & others, 1998b) revealed that 43% of the *in vivo* Class II hybrid composite restorations were overfilled and 25% were underfilled. Marginal imperfection will accelerate plaque retention and subsequently induce the occurrence of secondary caries and gingivitis. Use of the new-generation dentin bonding agents has been advocated to increase bond strength and marginal sealing (Pashley & others, 1995). However, polymerization shrinkage of composite materials yields a high contraction stress and induces debonding from the restorative interface (Davidson & Feilzer, 1997).

Since 1996, a new class of "flowable composites" has been marketed. With the flow characteristic differing from that of hybrid composites, flowable composites can be easily placed and adapted to cavity surfaces by the injection technique. According to Bayne and others (1998), flowable composites can be applied to initial Class I and II composite fillings, and potentially be used as a lining under hybrid composites in cavities with difficult access. The authors' earlier work (Chuang, Liu & Jin, 2001) examined the effect of flowable composite lining on marginal microleakage and internal voids of Class II resin restorations. Results showed the benefit of flowable composite linings was restricted to reducing internal porosities. No improvement in cervical marginal sealing was observed. Labella and others (1999) revealed the potential risk of increasing polymerization shrinkage using flowable composite materials. More matrix content in flowable composites compared to hybrid composites typically leads to greater polymerization shrinkage, and potentially, interfacial bonding failure. Other researches (Leevailoj & others, 2001; Wibowo & Stockton, 2001) recently have also reported that the use of flowable composite lining under hybrid composite did not effectively eliminate microleakage at cervical margins.

Recently, a new technique called the "modified incremental layering technique" for restoring Class II composites restorations was presented (Jackson & Morgan, 2000). A thin layer of flowable composite is applied to the cavity floor and is immediately followed by packable composite increment. Then, these two materials are simultaneously light cured. Most of the flowable composites are expelled, while placing overlaying composites and their volume can be minimized. This technique offers the advantage of two different composites, including intimate adaptation of filling and improved handling properties. Since the new technique has not yet been experimentally tested, it was hypothesized that some problems were probably associated with it, such as porosity generation during condensation, marginal overhang after vigorous compression of the overlaying increment, its marginal sealing effect and lack of durability of thin, flowable composite linings after aging.

Accordingly, this *in vitro* study compared Class II composite restorations using flowable composite linings either with the modified incremental layering technique or with various thicknesses by evaluating cervical marginal microleakage, internal voids and cervical marginal morphology before and after the thermocycling test.

METHODS AND MATERIALS

Thirty-two intact human molars without decay or previous restoration were chosen. They were cleaned and examined for cracks under a stereomicroscope. Before testing, they were stored in normal saline at 5°C within four months of extraction. Each tooth was mounted in a stone jig with one premolar and one molar on the mesial and distal sides to simulate posterior tooth alignment. Two box-only Class II cavities (with 4 mm of bucco-lingual width and 2 mm of mesio-distal depth) were prepared on the mesial and distal surfaces of each tooth. The margins were all located on enamel and were 1-1.5 mm above the cementoenamel junction (CEJ). All the cavosurface margins were kept as butt-joint. The cavities were prepared using diamond burs (Shofu #440M and #411, Shofu Inc, Japan) and each bur cut fewer than 10 cavities. Prior to filling, each tooth was wrapped with a Tofflemire metal matrix and a matrix retainer, using wooden wedges (Hawe-Neos Dental, Biogglio, Switzerland) inserted interproximally in order to tightly seal the cervical margins. A sharp explorer was used to confirm the fitness between the metal matrix and cervical margin.

The same operator performed all restorative procedures. Flowable composite Filtek Flow (3M ESPE, St Paul, MN, USA, Lot #OAL), posterior composite Filtek P60 (3M ESPE, Lot #OCG) and their compatible dentin bonding agent Single Bond (3M ESPE, LOT #OEJ) were selected as test materials. The teeth were randomly assigned to four test groups (n=16 cavities per group). All teeth were restored using the same materials and etching-bonding system, but with various thicknesses of flowable composite lining and different restorative techniques.

Group 1 (P60 alone): The cavities were etched with 35% phosphoric acid (Ultraetch, Ultradent, South Jordan, UT, USA, #3F51), water rinsed for 15 seconds and air blasted to remove excess water. Two layers of single-component dentin bonding agent, Single bond, were applied to the whole cavity surface, and each layer was light-cured with XL3000 (3M ESPE) for 10 seconds according to the manufacturer's instructions. The cavities were restored with Filtek P60 composite using the horizontal incremental technique, with each increment about 2.0-mm thick. Each increment of composite was light cured from the occlusal aspect for 20 seconds. After the wooden wedge and metal matrix were removed, each restoration was light cured via the buccal and lingual aspects for 20 seconds.

Group 2 (ultrathin lining/co-cured): The cavities were etched, applied with dentin bonding agent and light cured with the same protocols as Group 1. The operator measured the original depth using a periodontal probe. Flowable composite Filtek Flow was injected onto the floor of the cavity to a thickness of 0.5 to 1.0 mm. The thickness of the flowable composite was controlled, referring to the original cavity depth. Immediately following the flowable composite lining, the first Filtek P60 increment, 2-mm thickness, was inserted and packed to expel flowable composite materials as previously described (modified incremental layering technique.) The expelled flowable composite was carefully cleaned with a microbrush. Two layers of resin were then light cured simultaneously for 20 seconds. The remaining cavity was incrementally filled with P60 and each increment light-cured for 20 seconds.

Group 3 (thin lining/pre-cured): After etching and treating with dentin bonding agent, a 0.5- to 1.0-mm layer of Filtek Flow was injected onto the cavity floor and immediately light cured for 20 seconds. The cavity was then incrementally filled with P60 and light cured as stated above.

Group 4 (thick lining/pre-cured): The restorative procedures were similar to Group 3 except that the thickness of the flowable composite lining was increased to approximately 2 mm.

Following completion of the restoration, it was finished with a fine diamond bur (SF 104R, Shofu, Japan) and polished with a series of sandpaper disks (Sof-Lex, 3M ESPE). Care was taken to avoid polishing the cervical margin. The teeth were then removed from the stone jigs and washed under tap water. The restorations were cleaned with 37% phosphoric acid for five seconds to remove the smear layer, water-rinsed and air dried. Impressions of the restoration surface were taken with poly(vinylsiloxane) light-body materials (President, Colténe, Altstätten, Switzerland, KB129) and poured with low-viscosity epoxy resin (Epo-Thin, Buehler, USA) to produce positive replicas of the restoration surfaces before the thermocycling tests. Subsequently, the teeth were placed in isotonic saline in a water bath at 37°C for 24 hours and thermocycle tested for 1500 cycles from 5°C to 60°C, with a dwelling time of 20 seconds for each temperature. Impressions were taken again and poured into replicas of the restorations after thermocycling. These replicas were examined by scanning electron microscope (SEM) for marginal micromorphology.

Interface Microleakage and Internal Voids Evaluation

The root apexes of these teeth were sealed with wax, and all the surfaces were coated with two layers of nail varnish from 1 mm beyond the restorations. The teeth were soaked in 1% basic fuchsin dye in a 37°C water bath for 24 hours. After removal from the dye solution, they were mesio-distally sectioned into halves along their long axis using an Isomat 2000 precision saw (Buehler, USA). Each group included 32 sectioned halves and each half was examined with a 50x stereomicroscope (StemiSV6, Zeiss, Germany). The cervical

marginal microleakage was recorded based on the following criteria (Figure 1A):

Score 0 = no dye penetration

Score 1 = dye penetration limited to enamel

Score 2 = dye penetration beyond the dentino-enamel junction, but limited to 2/3 of the cervical wall length

Score 3 = dye penetration beyond 2/3 of the cervical wall length, but not to the pulpal wall

Score 4 = dye penetration to the pulpal wall

As in a previous study (Chuang & others, 2001), the internal voids were recorded according to location: interface void at the restorative interface of the cervical margin, cervical void in the cervical half and occlusal void in the occlusal half of the restorations (Figure 1A). These locations were evaluated as score 0 = no void and score 1 = visible voids. The cervical marginal microleakage and each part of the internal void were analyzed using the Mann-Whitney test with p=0.05 significance level.

SEM Examination of Cervical Marginal Micromorphology

The replicas of the restorations before and after thermocycling were mounted on aluminum stubs and submitted to gold-sputter coating. Each replica was examined and recorded using SEM (S-2500, Hitachi, Japan) with a 50x magnification and verified with 200x and 500x, if necessary (Figure 1B). The cervical marginal micromorphology of each restoration was divided into five patterns: perfect, deficient, opening, overhanging and swelling margins, with the former three considered as indicators of marginal integrity. The five micromorphology patterns are demonstrated in Figures 2 and 3. The length of each pattern was measured with image software and quantitatively assessed as percentages of the total cervical wall length on the microphotographs. Cervical marginal morphology was compared across the groups using the one-way ANOVA test. For each group, morphological changes during thermocycling tests were analyzed by the paired t-test at the significance level of p=0.05.

RESULTS

Interface Microleakage Evaluation

One of the restorations in Groups 2 and 4 was destroyed during the tooth sectioning procedure and recognized as missing. Table 1 lists distribution of the cervical interface microleakage in each group as evaluated by the dye penetration score. None of these experimental groups presented complete marginal sealing. Group 2 included the most specimens (11/31), with complete marginal sealing (Score 0), and showed superior marginal quality over the other three groups (p<0.05). More than half of the specimens in Group 4 showed moderate to severe dye penetration (Score 2 to 4), resulting in significantly inferior marginal sealing compared to Groups 2 and 3.

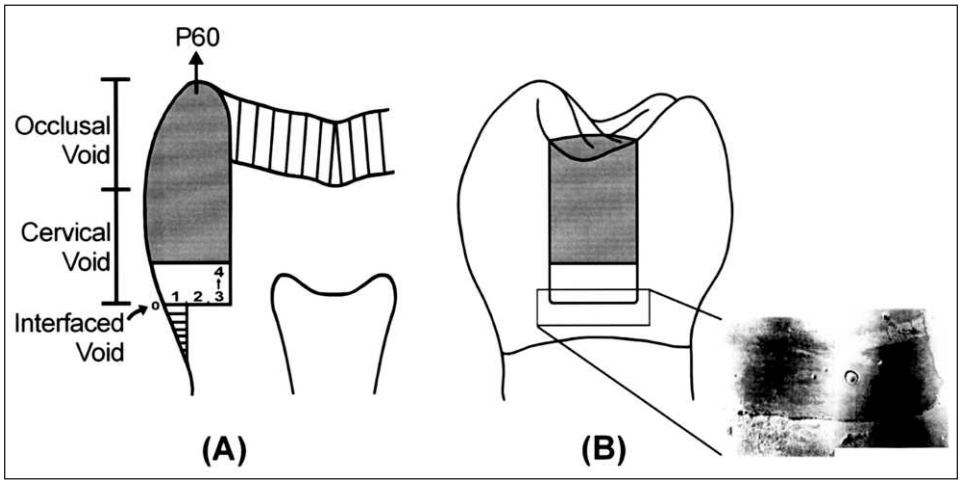

Figure 1. A-*Assessment protocols of interface microleakage and internal voids for the sectioned restorations. Interface microleakage was evaluated as an ordinal score from 0 to 4. Internal voids were evaluated according to the presence of voids in cervical interface, cervical and occlusal halves. B-SEM observation of the cervical micromorphology.*

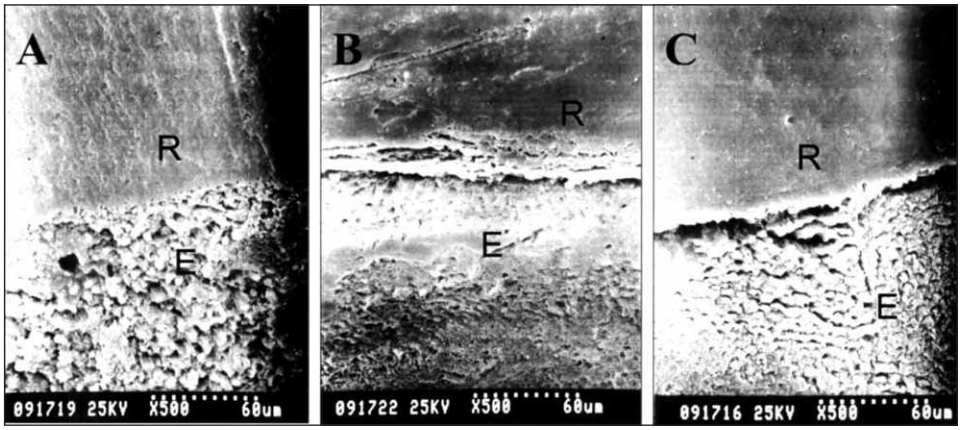

Figure 2. *SEM showing different types of cervical marginal morphology related to marginal integrity: Figure 2A, perfect margin; Figure 2B, deficient margin; Figure 2C, opening margin. R: resin composite, E: enamel. (Magnification: 500x).*

Internal Voids Evaluation

Table 2 lists the measurement of internal voids, including the interface, cervical and occlusal void. Both pre-cured groups (Groups 3 and 4) were free of voids in the cervical wall interfaces. Group 1 included significantly more interface voids than the other three groups ($p<0.05$). In part of cervical void, Group 4 showed the most specimens free of cervical voids, followed in order by Groups 3, 2 and 1. No significant difference was found when comparing the occlusal voids among these groups.

SEM Examination of Cervical Margin Micromorphology

Some restorations failed to be replicated in each group. From the effective replicas, the length of five types of margins (perfect, deficient, opening, overhanging and swelling) were measured as percentages of the total cervical wall length from the SEM microphotographs (Table 3). There was no significant difference in the marginal integrity among the four groups before thermocycling, except for the higher percentage of opening margin in Group 4 compared to Group 1 ($p=0.004$). After thermocycling, Group 4 displayed a significantly higher percentage of opening margins than the other groups. Meanwhile, Group 4 showed the lowest percentage of perfect margins.

At least 28% of the cervical wall lengths were recorded as overhanging margin in each group either before or after thermocycling. Group 2 showed a higher percentage (over 40%) of overhanging margins in both measurements but was not significantly different from the other groups. Group 1 exhibited the highest swelling margin percentage both before and after thermocycling.

Paired *t*-test was performed to examine the cervical marginal change of each group during thermocycling. The impact of thermocycling on each group was not consistent. Most groups presented insignificant changes in their marginal patterns, except for a noteworthy reduced perfect margin percentage in Group 4, following thermocycling.

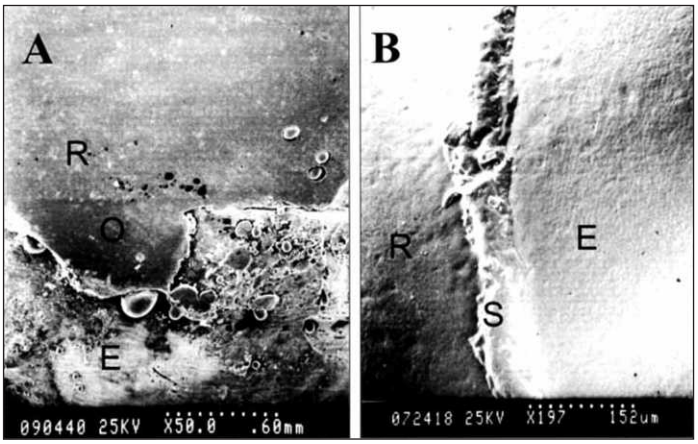

Figure 3. *SEM showing the overhanging and swelling margins. Figure 3A, overhanging margin is indicated with "O" for the overhanging of resin composite over the enamel surface. (Magnification: 50x). Figure 3B, swelling margin is indicated with an "S" for the expansion change of interface between resin composite and enamel. R: resin composite, E: enamel.*

Table 1: *Distribution and Analysis of Cervical Marginal Microleakage by the Mann-Whitney Test*

	Cervical Marginal Microleakage[1]				
	0	1	2	3	4
Group 1 (P60 alone) n = 32	8	14	4	4	2
Group 2 (ultrathin lining/co- cured) n =31	11	18	2	0	0
Group 3 (thin lining/pre-cured) n =32	2	27	3	0	0
Group 4 (thick lining/pre-cured) n =31	4	11	10	5	1

[1] *Significant difference was found between Groups 1 and 2 (p=0.044), Groups 2 and 3 (p=0.012), Groups 2 and 4 (p=0.000), as well as Groups 3 and 4 (p=0.006).*

Table 2: *Distribution and Analysis of Internal Voids (Interface void, Cervical void, and Occlusal void) by the Mann-Whitney Test*

	Interface Void[1]		Cervical Void[2]		Occlusal Void[3]	
	0	1	0	1	0	1
Group 1 (P60 alone) n = 32	16	16	2	30	2	30
Group 2 (ultrathin lining/co-cured) n =31	27	4	4	27	4	27
Group 3 (thin lining/pre-cured) n =32	32	0	12	20	3	29
Group 4 (thick lining/pre-cured) n =31	31	0	15	16	3	28

[1] *Significant difference was found between Groups 1 and 2 (p=0.002), Groups 1 and 3 (p=0.000), Groups 1 and 4 (p=0.000), Groups 2 and 3 (p=0.037), as well as Groups 2 and 4 (p=0.040).*

[2] *Significant difference was found between the comparisons of Groups 1 and 3 (p=0.003), Groups 1 and 4 (p=0.000), Groups 2 and 3 (p=0.026), as well as Groups 2 and 4 (p=0.003).*

[3] *No significant difference.*

DISCUSSION

In this study, the thickness of flowable composite was assumed to affect the quality of the overall restorations. Class II composite restorations with thin and thick lining were evaluated with respect to cervical marginal microleakage, internal voids and exterior marginal morphology.

In Group 2, teeth restored with an ultrathin flowable composite lining displayed the best interface marginal quality, while those teeth with a thick lining (Group 4), presented the worst. The formation of marginal microleakage may contribute to the interaction of polymerization shrinkage, bonding strength, hygroscopic expansion and other occurring factors. The main difference among the groups in this study was the thickness of flowable composite, since the dentin bonding agents and composites used were identical. Results from a previous study showed that flowable composites exhibited higher polymerization shrinkage than their hybrid analogs (Labella & others, 1999). Accordingly, more marginal microleakage may increase with the thickness of flowable composite linings, as shown in this study. Also, some researchers considered a thick lining of low modulus material could serve as a flexible intermediate layer to relieve contraction stress from the overlaying composite (Kemp-Scholte & Davidson, 1990). However, this assumption has not yet been proven. Results of this study show that flowable composite lining should be kept as thin as possible to reduce microleakage.

The internal voids in these groups predominantly consist of interface and cervical voids. Restorations without flowable composite lining (Group 1) showed high prevalence of interface and cervical voids. The presence of voids may contribute to the deficient cavity adaptation and unavoidable trapping of air while manipulating a posterior composite. Group 2 results indicated that the incidence of interface and cervical voids decreased with the application of flowable linings, but remained higher than the pre-cured groups (Groups 3 and 4). Packing an overlaying composite into the lining composite may cause a blending motion that incorporated air into the bottom layer of the restoration. Group 2 exhibited a moderate incidence of interface voids but good marginal sealing in this study. The marginal integrity in Group 2 mainly resulted from the enhanced cavity adaptation and may partly contribute to these minimal voids. Alster and others (1992) has demonstrated reduced contraction stress could be obtained by using a thin, pore-containing lining layer. Both the presence of these minimal voids and the setting inhibition effect caused by their containing oxygen may provide relief polymerization stress and result in reduced microleakage. However, care must be taken to trap air during placement of the flowable composite. The repeated packing motion following placement of the overlaying composite must be avoided to prevent undue porosity formation.

Surface marginal micromorphology of the restoration and its changes during the thermocycling test were observed using the replica fabrication technique. This technique allows the surface morphology of a single restoration to be repeatedly observed without destruction (Krejci, Besek & Lutz, 1994). The image that was obtained was distinct even at 1000x magnification and could be quantitatively evaluated. SEM observation showed Group 4 displayed the highest percentage of opening margins both before and after thermocycling and the lowest percentage of perfect margins after thermocycling. This finding was consistent with the results of interface microleakage that were obtained from the sectioned surface. Moreover, Group 4 displayed significant reduction in the percentage of perfect margins during thermocycling. This finding implied a thick flowable composite lining tends to be damaged by thermocycling.

Another marginal problem studied here was the overhanging margin. Cervical over-extension of a restoration may lead to plaque retention, periodontal problems and marginal chipping. Previous *in vivo* research has reported overfilling in up to 43% of restorations according

Table 3: *Mean ± standard error of length percentages (%) for each marginal pattern of the experimental groups. Inter-group comparisons of marginal micromorphology were analyzed by one-way ANOVA test[1]. Comparison between before and after thermocycles within the same group was performed by pair* t-*test[2].*

	Before Thermocycles				After Thermocycles			
	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
	n = 15	n = 16	n = 16	n = 16	n = 13	n = 13	n = 15	n = 14
Marginal integrity								
Perfect margin	10.79 ± 4.71^{a}	15.65 ± 4.41^{a}	9.05 ± 2.81^{a}	8.56 ± 3.00^{a}	12.58 ± 3.55^{a}	10.94 ± 3.23^{ab}	5.31 ± 1.85^{ab}	4.73 ± 1.83^{b}
Deficient margin	34.42 ± 6.01^{a}	25.86 ± 5.08^{a}	36.87 ± 6.17^{a}	39.60 ± 5.33^{a}	26.91 ± 6.93^{a}	28.78 ± 6.76^{a}	40.69 ± 6.31^{a}	38.88 ± 5.24^{a}
Opening margin	1.88 ± 1.05^{a}	12.74 ± 6.37^{ab}	10.67 ± 3.01^{ab}	21.19 ± 4.54^{b}	6.54 ± 2.95^{a}	13.76 ± 4.66^{a}	9.14 ± 1.85^{a}	23.94 ± 6.38^{b}
Overhanging margin	32.56 ± 5.05^{a}	43.18 ± 7.74^{a}	36.57 ± 6.42^{a}	28.54 ± 5.24^{a}	28.97 ± 5.45^{a}	42.15 ± 9.15^{a}	34.94 ± 6.91^{a}	28.80 ± 5.12^{a}
Swelling margin	20.35 ± 6.25^{a}	2.47 ± 2.47^{b}	6.84 ± 4.16^{b}	2.11 ± 1.24^{b}	25.01 ± 10.13^{a}	4.37 ± 2.50^{b}	9.91 ± 3.90^{b}	3.65 ± 2.51^{b}

[1] *Length ratio of each marginal pattern by one-way ANOVA test was ranked with the superscripted alphabets. Identical alphabets indicate no significant difference.*

[2] *Significant difference in change during thermocycling test was found in the perfect margin of Group 4 (p=0.009).*

to SEM observation (Opdam & others, 1998b). In the current study, the lining flowable composite was expelled during the forced packing of overlaying P60 in Group 2. The extruded material raised the concern of increasing the likelihood of marginal over-extension. In this study, no significant difference was detected among these groups, despite Group 2 exhibiting a higher percentage of overhanging margins. However, clinicians must recognize the risk of increasing marginal overhang when using this new modified incremental technique. Based on the results, a cautious examination of the cervical margin overhang would be recommended.

The swelling change of the restorative margin was significantly higher in Group 1 than in other groups. The swelling margin represented hygroscopic expansion of a bonding agent or resin composite (Hansen & Asmussen, 1989). According to Thonemann and others (1997), marginal expansion can be regarded as an early sign of insufficient adhesion of the composite at sites where the bond was initially disrupted. The subsequent hydrolytic degradation of the composite in these areas causes marginal gaps. The main difference between Group 1 and the other groups was the absence of a lining in that group to buffer the expansion stress of the materials at the interface, which caused swelling. Thus, marginal swelling was considered a potential restoration problem.

Since Bayne and others (1998) suggested the practicality of using flowable composites as the lining in resin composite restorations, some recent clinicians and researches have followed-up on this claim. In packable composite restorations, additional flowable composite lining was found to favorably improve marginal sealing (Leevailoj & others, 2001). In the current study, the restorative composite P60 was classified in this category since its monomer composition was altered to increase viscosity (Peumans & others, 2001). This study demonstrated improved marginal sealing by combining P60 and a particularly thin flowable lining over P60 restoration, alone. The improvement apparently followed the increased cavity adaptation of the additional lining.

CONCLUSIONS

Results from previous studies revealed that using flowable composite improved cavity adaptation, however, at the risk of increasing polymerization shrinkage. In this study, the use of flowable composite lining significantly reduced the incidence of voids in the restorative interface but did not consistently improve the marginal integrity. Restorations lined with thick, flowable composite lining exhibited reduced perfect margin percentage and the potential risk of marginal degradation. To the contrary, restorations filled with the new modified incremental technique (Group 2) presented reduced interface microleakage and superior cervical marginal sealing but with only minimal internal voids. The greatest concern in the new modified incremental technique is addressed in the tendency to increase overhanging margins. Based on the results of this study, the technique is recommended as simply and practically applicable to Class II resin restorations.

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Aggressiveness of Self-etch Adhesives on Unground Enamel

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Clinical Relevance

The microtensile bond strengths of aggressive self-etch adhesives to unground enamel were not significantly different from total-etch adhesives. Aggressive self-etch adhesives are potentially useful for bonding to unground enamel such as that present in occlusal fissures, in conjunction with the use of pit-and-fissure sealants and for the bonding of orthodontic brackets.

SUMMARY

Manufacturers of mild self-etch adhesives advocate the adjunctive use of phosphoric acid etching when bonding to unground enamel. This study tested the null hypothesis that there is no difference between the recently introduced, more aggressive self-etch adhesives and a total-etch adhesive in bonding to unground enamel. The ultrastructure and microtensile bond strengths (μTBS) of Xeno III (Dentsply) and Simplicity (Apex Dental Materials), bonded to unground enamel, were examined after thermocycling. Clearfil SE Bond (Kuraray), a mild self-etch adhesive, was used as the negative control, and One-Step (BISCO), a total-etch adhesive bonded to phosphoric acid-etched unground enamel, was used as the positive control. Differences in the thickness of enamel hybrid layers were observed and the aggressiveness of apatite dissolution in the four adhesives.

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INTRODUCTION

Self-etch dentin adhesives are becoming increasingly popular in restorative dentistry, preventive dentistry and orthodontics. With water being an integral component in these non-rinsing adhesives (Tay & Pashley, 2001), the ambiguity in providing the optimal moisture condition for maintaining the integrity of a demineralized collagen matrix in the total-etch technique is eliminated (Pioch & others, 2002). Post-operative sensitivity associated with removal of the smear layer and smear plugs is also reduced when non-rinsing adhesives are used for dentin bonding (Brunton & others, 1999). Two-step self-etching primers have been further simplified into one-step all-in-one adhesives that etch, prime and bond simultaneously (Inoue & others, 2001; Perdigão, 2002). The prospective uses of self-etch adhesives would be even more promising if they are equivalent in performance for clinical procedures such as bonding of pit-and fissure sealants (Gillet & others, 2002) or orthodontic brackets (Bishara & others, 2002), where conventional phosphoric acid-etching is still used as the mainstream technique.

Self-etch adhesives may be classified into mild, moderate and aggressive, depending on the acid dissociation constants (pKa values) of the acidic resin monomers employed and the concentration of these monomers in the adhesives (Pashley & Tay, 2001; Muecke & others, 2003). Unlike bonding to dentin, the application of self-etch adhesives to enamel has been a controversial issue, particularly when mild self-etch adhesives are used on unground enamel. Whereas some studies supported the manufacturers' recommendations that the adjunctive use of phosphoric acid-etching is necessary when bonding to this substrate (Kanemura, Sano & Tagami, 1999; Pashley & Tay, 2001), others showed that there were no differences among the bond strengths of mild self-etch and total-etch adhesives to unground enamel (Fritz, Diedrich & Finger, 2001; Ibarra & others, 2002; Shimada & others, 2002). Although well-defined enamel etching patterns and resin tag formation are not prerequisites for achieving strong initial enamel bonds (Perdigão & others, 1997; Hobson & McCabe, 2002), they have been associated with the stability (Torii & others, 2002) and improved survival rate of enamel bonds created *in vivo* (Hobson, McCabe & Rugg-Gunn, 2002). Thin lamina-like resin penetration produced on unground enamel with mild self-etch adhesives may not sustain cyclic stresses as favorably as deeper resin infiltration in the prismatic enamel that is promoted by the use of more aggressive self-etch adhesives or phosphoric acid-etching.

Although bonding to uncut enamel in restorative dentistry may be largely circumvented with the use of beveled enamel margins (Opdam & others, 1998; Hoelscher & others, 2000), such a procedure is not always employed by clinicians, particularly in small cavity preparations. Moreover, as more aggressive self-etch adhesives are introduced, their uses have been extended to the bonding of orthodontic brackets (Arnold, Combe & Warford, 2002; Velo, Carano & Carano, 2002), which invariably involves adhesion to unground enamel. This study examined the ultrastructure and microtensile bond strengths of self-etch adhesive-bonded unground enamel after thermocycling. The null hypothesis tested was that there is no difference between the more aggressive self-etch adhesives and a total-etch adhesive in the capacity to bond to unground enamel.

METHODS AND MATERIALS

Extracted human molars were collected after the patients' informed consent had been obtained under a protocol reviewed and approved by the institutional review board from the Medical College of Georgia, USA. The mesial and distal surfaces of these teeth were cleaned with cotton gauze and ethanol. The unground enamel surfaces were examined under a stereomicroscope to ensure that they were free of surface cracks, decalcification or any sign of previous grinding.

Experimental Design

Three self-etch adhesives and a total-etch adhesive were examined using the bonding protocols summarized in Table 1. Clearfil SE Bond (Kuraray Medical Inc, Tokyo, Japan), a mild, two-step self-etch adhesive in which adjunctive phosphoric acid-etching is advocated by the manufacturer for bonding to unground enamel, was used as the negative control. Xeno III (Dentsply DeTrey, Konstanz, Germany), a one-step self-etch adhesive, and Simplicity (Apex Dental Materials Inc, Schaumburg, IL, USA), a two-step self-etch adhesive, were examined. One-Step (BISCO Inc, Schaumburg, IL, USA), a two-step total-etch adhesive, was applied to 32% phosphoric acid-etched unground enamel as the positive control. For standardization, phosphoric acid was applied for the same period (20 seconds) as the self-etching components of the self-etch adhesives.

Transmission Electron Microscopy (TEM)

To compare the etching effect on unground enamel, the self-priming component from each of the three self-etch adhesives and the phosphoric acid etchant were applied individually to the mesial and distal enamel surfaces of a molar. After rinsing with distilled water, a 0.9-mm thick slab was prepared mesio-distally along the mid-coronal part of each tooth, using a slow-speed diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA) under water-cooling. The slabs were then sonicated in 70% ethanol for 60 seconds to remove remnant resinous components and cutting debris from the etched surfaces. The specimens were dehydrated and embedded in epoxy resin using the TEM protocol reported by Tay, Moulding and Pashley (1999). Undemineralized 90-120-nm thick sections were examined unstained using a TEM (Philips EM208S, Philips, Eindhoven, The Netherlands) operated at 80 kV.

Two additional molars were used for each adhesive to examine the thickness of the hybrid layers and the ultrastructural appearance of the etched apatite crystallites after adhesive infiltration. To facilitate ultramicrotomy, the bonded enamel surfaces were coupled with 2-mm thick layers of a light-cured lining composite (Protect Liner F, Kuraray Medical Inc). The teeth were then subjected to cyclic thermal stresses (5°C and 55°C for 1,000 cycles in water). Composite-enamel blocks were harvested and sectioned for TEM examination without additional epoxy resin embedding. This was to take advantage of the stiffness/toughness mismatch (Broom & others, 1996) that causes delamination of the more resilient hybridized dental tissues from the underlying brittle, undemineralized dental tissues during dehydration and ultramicrotomy (Agee & others, 2003). Undemineralized TEM sections were also examined without further staining.

The thickness of the hybrid layers created by each adhesive was assessed by taking 10 measurements from five digitized images using an image analyzing software (Leica Qwin; Leica Microsystems Imaging Solutions Ltd, Cambridge, UK). Non-parametric statistical analysis was performed with Kruskal-Wallis ANOVA on ranks and Dunn's multiple comparison tests with statistical significance set at α=0.05.

Microtensile Bond Strength Evaluation

Six additional molars were used for each adhesive. Bonded mesial and distal enamel surfaces were coupled to a hybrid composite (TPH; Dentsply DeTrey) that was light activated in five 1-mm thick increments. To avoid premature subsurface enamel fracture that may result from polymerization contraction of the composite, a pulse-delay curing technique (Kanca & Suh, 1999) was employed for the first composite layer, following the enamel bonding protocol described by Pashley and Tay (2001). After the thermocycling challenge described previously, two 0.9-mm thick slabs were sectioned from each tooth, from which a 0.9x0.9 mm composite-enamel beam was obtained from the region of least curvature along each bonded enamel surface. This procedure was undertaken to minimize the inclusion of curved bonding surfaces during microtensile bond testing (Ibarra & others, 2002). The 24 beams from each adhesive group were stressed to failure using a universal testing machine (Model 4440, Instron Inc, Canton, MA, USA) at a crosshead speed of 1 mm/minute, using the "non-trimming" version of the microtensile test reported by Pashley and others (1999). Bond strength data were analyzed using one-way ANOVA and Tukey's multiple comparison tests, with statistical significance set at α=0.05. Linear regression analysis was also performed to determine the correlation between mean hybrid layer thickness and mean bond strength in these adhesives.

RESULTS

Figure 1 shows the etching effect of the self-etch adhesives and phosphoric acid. Etching was confined to aprismatic enamel in Clearfil SE Bond and Xeno III, creating

Table 1: *Thickness of the Enamel Hybrid Layer and Microtensile Bond Strengths Obtained After the Application of the Various Self-etch and Total-etch Adhesives to Unground Human Enamel*

Adhesive	Lot #	Bonding Protocol	Thickness of Enamel Hybrid Layer (N=10)* [µm]	Microtensile Bond Strength (N=24)** [MPa]
		2-step Self-etch Adhesive		
Clearfil SE Bond (Kuraray Medical Inc) [negative control]	Primer: 00183A Bond: 00173A	1. Apply primer 20 seconds 2. Air-dry 3. Apply bonding resin 4. Air dry 5. Light-cure 10 seconds	0.33±0.13^{A}	16.9±4.0^{1}
		1-step self-etch adhesive		
Xeno III (Dentsply DeTrey)	Bottle A: 0206000382 Bottle B: 0206000381	1. Mix components dispensed from two bottles 2. Apply mixed adhesive 20 seconds 3. Air-dry 4. Light-cure 10 seconds	1.00±0.15^{A,B}	30.7±8.0^{2}
		2-step self-etch adhesive		
Simplicity (Apex Dental Materials Inc)	Simplicity 1: 00026 Simplicity 2: 00125	1. Apply self-priming conditioner 20 seconds 2. Blot dry with foam pellet 3. Apply bonding adhesive 4. Light-cure 10 seconds	3.32±0.53^{B,C}	28.8±8.4^{2}
		2-step total-etch adhesive		
One-Step (BISCO, Inc) [positive control]	Etchant: 0200004312 Single-bottle adhesive: 0006466	1. Acid-etch with 32% phosphoric acid 20 seconds, rinse 2. Air-dry 3. Apply adhesive, air-dry 4. Light-cure 10 seconds 5. Reapply uncured adhesive before composite coupling	9.57±1.27^{C}	29.4±8.9^{2}

**Non-parametric statistical analysis performed using Kruskal-Wallis analysis of variance on ranks and Dunn's multiple comparison tests. Groups indicated by different letter superscripts are significantly different (p<0.05)*

***Parametric statistical analysis performed using one way analysis of variance and Tukey's multiple comparison tests. Groups indicated by different numeric superscripts are significantly different (p<0.001)*

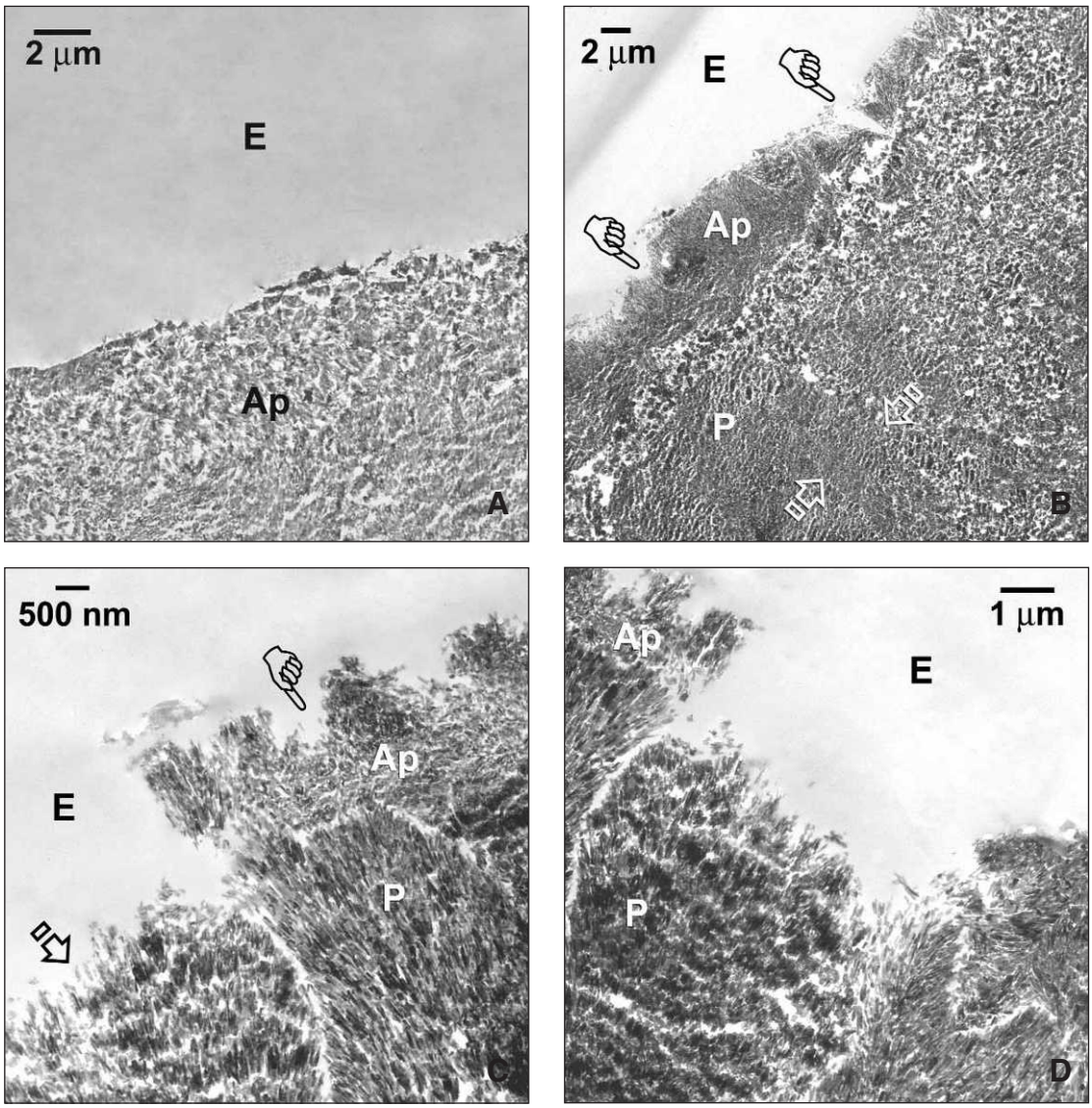

Figure 1. *Unstained, undemineralized TEM micrographs illustrating the surface etching effect produced by self-etch adhesives and 32% phosphoric acid for the same period of time (20 seconds) on unground enamel. A. Clearfil SE Bond, a mild two-step self-etch adhesive (negative control). B. Xeno III, a one-step self-etch adhesive. C. Simplicity, a two-step self-etch adhesive. D. Phosphoric acid-etched unground enamel (positive control). For the self-etch adhesives, the unpolymerized self-etching components were either rinsed off or dissolved in ethanol after etching before embedding in epoxy resin (E). Ap: aprismatic enamel; P: prismatic enamel. A. For Clearfil SE Bond, the aprismatic enamel surface was barely etched. B. For Xeno III, the etching effect was localized to the surface aprismatic enamel. This surface was partially dissolved, with shallow depressions created also within the aprismatic enamel. Enamel prisms, about 5 μm in diameter (between open arrows), could be seen in the underlying prismatic enamel pointers. C. For Simplicity, both the aprismatic and prismatic enamel were exposed. Depressions were evident in the aprismatic enamel (pointer) and the underlying exposed prismatic enamel was also differentially etched (open arrow). D. For phosphoric acid-etched unground enamel [D], the aprismatic enamel was also completely dissolved in some areas, exposing the underlying prismatic enamel.*

a minimally etched surface in the former, (Figure 1A), and a more aggressively etched surface with shallow depressions in the latter (Figure 1B). Part of the surface aprismatic layer was completely dissolved in Simplicity (Figure 1C), and after phosphoric acid etching (Figure 1D) with the exposed prismatic enamel differentially etched along prism cores or boundaries.

Figure 2 shows the enamel hybrid layers created by infiltration of the self-etch and total-etch adhesives. Only aprismatic enamel was included in the hybrid layers created by Clearfil SE Bond (Figure 2A) and Xeno III (Figure 2B). Both aprismatic and prismatic enamel were observed in the hybrid layers formed by Simplicity (Figure 2C) and One-Step (Figure 2D), with resin tags along the base of the hybrid layers forming negative impressions of the etching patterns in prismatic enamel. No significant differences were observed in the thickness of the hybrid layers created between Clearfil SE Bond and Xeno III, between Xeno III and Simplicity and between Simplicity and One-Step (Table 1).

Ultrastructural appearance of the etched and bonded apatite crystallites are depicted in Figure 3. The hybrid layer in Clearfil SE bond consisted mostly of a single layer of densely packed crystallites that exhibited minimal dissolution (Figure 3A). Crystallites were also closely approximated in Xeno III, with the superficial crystallites exhibiting evidence of dissolution along their external surfaces (Figure 3B). In Simplicity, the crystallites were more widely spaced (Figure 3C), with evidence of preferential core dissolution. In One-Step, crystallites from regions containing etched prismatic enamel were more disorganized. Preferential core dissolution was also

observed in the form of central hole defects (Daculsi, LeGeros & Mitre, 1989), exposing the central dark lines (Marshall & Lawless, 1981) in these biological apatites (Figure 3D).

Table 1 also shows the microtensile bond strengths of the four adhesives. The bond strengths of Xeno III, Simplicity and One-Step did not significantly differ from each other but were significantly higher than Clearfil SE Bond ($p<0.001$). There was no significant correlation between hybrid layer thickness and bond strength (r=0.46; $p=0.54$).

DISCUSSION

Apart from Clearfil SE Bond, there was no difference among microtensile bond strengths in Xeno III, Simplicity and total-etch adhesive One-Step despite the disparities of their etching capacities on unground enamel. As there was no difference between the two more aggressive self-etch adhesives and the total-etch adhesive regarding capacity to bond to unground enamel, the null hypothesis cannot be rejected.

The existence of a surface aprismatic enamel layer in both deciduous and permanent teeth has been well documented (Ripa, Gwinnett &

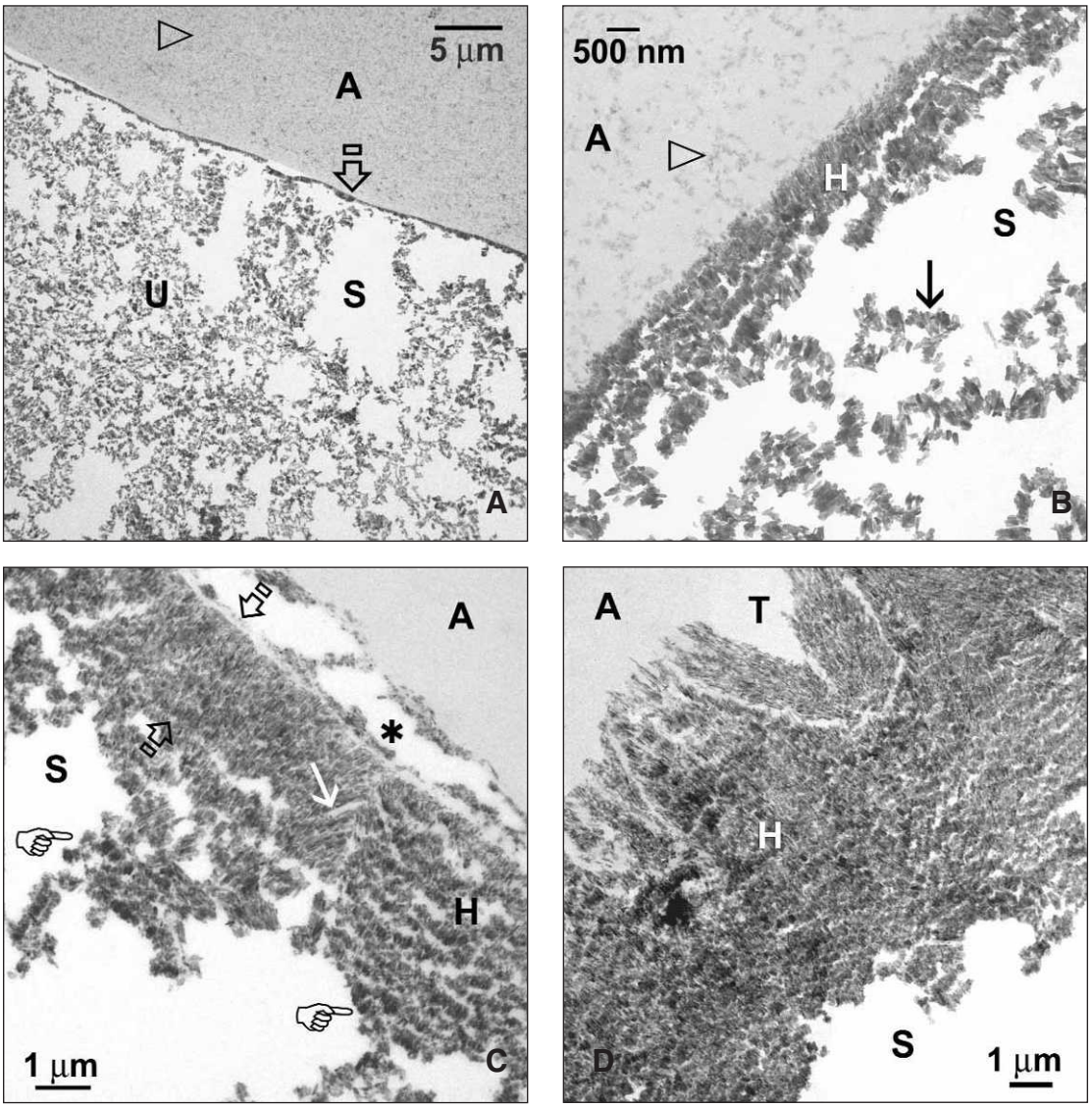

Figure 2. *Low magnification, unstained, undemineralized TEM micrographs illustrating the thickness of the enamel hybrid layer created in unground enamel following the application of different self-etch (non-rinsing) and total-etch (rinsed) adhesives. A. Clearfil SE Bond. B. Xeno III. C. Simplicity. D. One-Step on phosphoric acid-etched unground enamel. The resin-infiltrated hybrid layer was more resilient than the underlying unbonded enamel and separated from the latter during ultramicrotomy due to a stiffness-toughness mismatch, leaving behind empty spaces (S) beneath. A: Clearfil SE Bond produced only a 0.3 μm thick hybrid layer (open arrow) in aprismatic enamel. The loose, unsupported enamel crystallites from the unbonded enamel (U) were thinned out by surface tension over the formvar film of the copper grid, being separated by wide empty spaces. Open arrowhead: fumed silica clusters from the filled adhesive (A). B. Xeno III produced a 0.8-1.5 μm thick hybrid layer (H) in aprismatic enamel. Open arrowhead: fumed silica clusters from the filled adhesive (A). Arrow: loose agglomerates of enamel crystallites that were not infiltrated by the adhesive. C. The hybrid layer (H) in Simplicity was 2-4 μm thick and consisted of both aprismatic enamel (between open arrows) and prismatic enamel (arrow). Resin tags (pointers), consisting of resin-infiltrated enamel crystallites, were also created by differential etching of the prism boundaries (Type II etching pattern) in the exposed prismatic enamel. The unfilled adhesive (A) partially separated from the hybrid layer during ultramicrotomy, leaving behind an artifactual gap (asterisk). D. A 8-11 μm thick hybrid layer (H) was created after application of One-Step to phosphoric acid-etched enamel. The hybrid layer contained both prismatic and aprismatic enamel (not shown). Resin tags (T) that were devoid of enamel crystallites and consisted of only the unfilled adhesive (A), were formed by differential etching of the prism cores (Type I etching pattern) in the exposed prismatic enamel.*

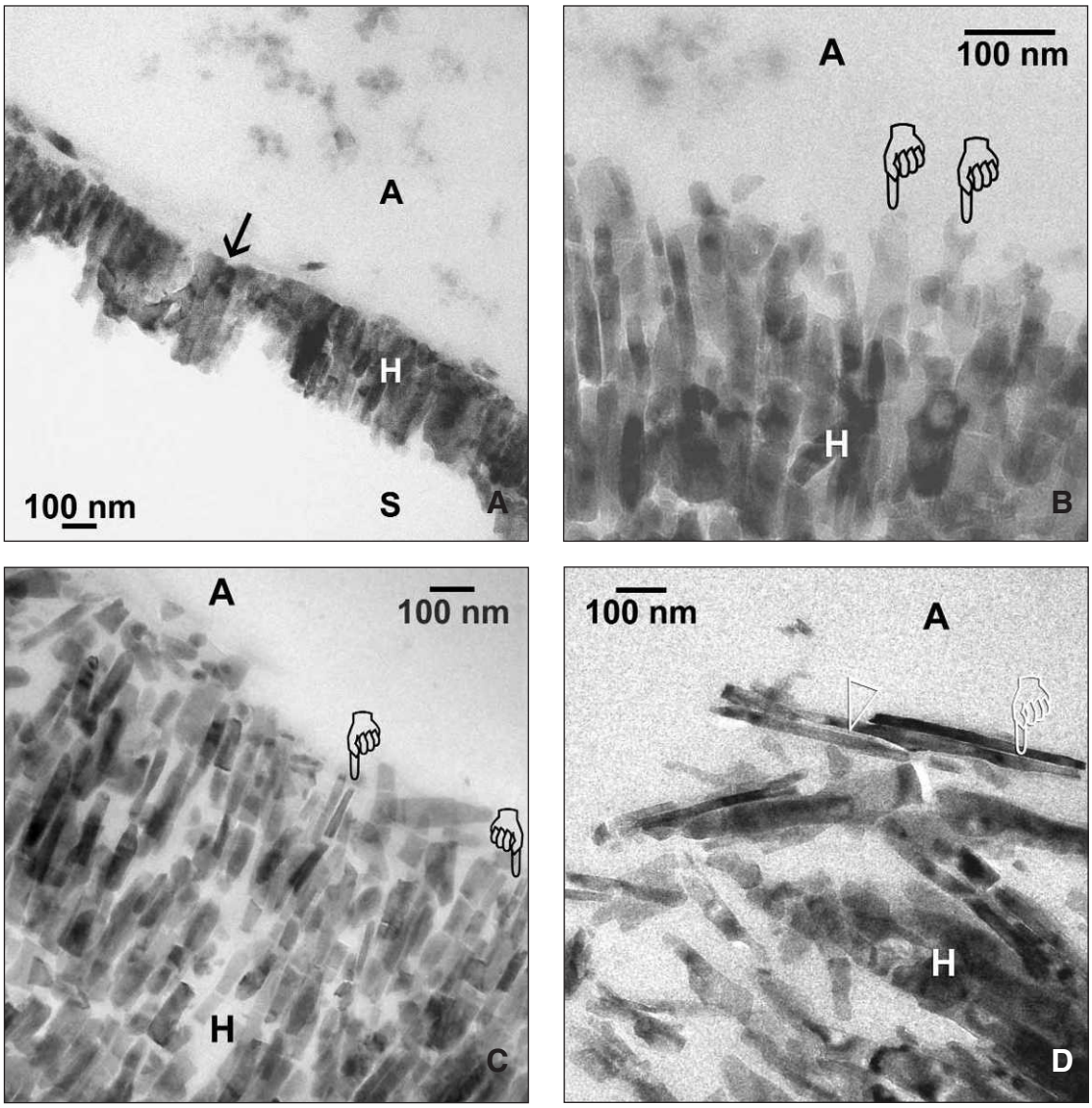

Figure 3. *High magnification, unstained, undemineralized TEM micrographs illustrating the aggressiveness of the various self-etch adhesives and phosphoric acid on the enamel crystallites along the surface of the enamel hybrid layer. A. Clearfil SE Bond. B. Xeno III. C. Simplicity. D. One-Step applied to phosphoric acid-etched unground enamel. A: adhesive; H: hybrid layer; S: empty space. A. The very thin hybrid layer created by Clearfil SE Bond consisted mostly of a single layer of densely packed, apatite crystallites that were oriented in a parallel fashion and exhibited minimal dissolution along their entire longitudinal axes (arrow). B. In Xeno III, the apatite crystallites in the aprismatic enamel were also closely packed together. More aggressive surface dissolution of some of the apatite crystallites could be seen along the top of the hybrid layer (pointers). C. In Simplicity, the enamel crystallites from a region of resin-infiltrated aprismatic enamel were also oriented in a parallel fashion, but were more widely separated from each other. Some crystallites from the surface of the hybrid layer exhibited central holes or defects (pointers) that were indicative of preferential dissolution within the core of the apatite crystallites. D. Apatite crystallites were disorganized and widely separated from one another along the surface of the hybrid layer in One-Step infiltrated, phosphoric acid-etched unground enamel. Crystallite dissolution occurred preferentially along the c-axis, producing central defects or holes (pointer) and exposing the central dark line in some of these crystallites (open arrowhead).*

Buonocore, 1966). An increasing degree of aggressiveness could be seen when the four adhesives were applied to unground enamel, producing minimal, partial or even localized complete dissolution of this surface aprismatic layer. The authors have previously reported that the use of a mild self-etch adhesive such as Clearfil SE Bond on unground enamel resulted in a minimally-etched surface with ill-defined etching patterns (Pashley & Tay, 2001). Hybrid layers formed by this adhesive on aprismatic enamel were also extremely thin. In a previous study, the bonded specimens were demineralized before TEM examination, with only stained enamel proteins remaining within the hybridized enamel. With the use of unstained, undemineralized sections in the current study, only apatite crystallites and possibly amorphous calcium phosphate reaction products were observed in the hybrid layer. The bond strength of Clearfil SE Bond to unground enamel was significantly lower than the other three adhesives. This is contrary to the results reported by Ibarra and others (2002), where the microtensile bond strength of this mild self-etch adhesive before thermocycling was not significantly different from other more aggressive self-etch and total-etch adhesives. Although lower bond strength to unground enamel may be attributed to weaker inherent strength of the polymerized adhesive (Pashley & Tay, 2001), it is still difficult to justify how a hybrid layer that consisted of a single layer of almost intact apatite crystallites could sustain cyclic and functional stresses, or orthodontic retraction forces in the

case of bonded brackets. The authors further speculate that more microleakage may be present when unground enamel sealed with this adhesive is subjected to occlusal stresses (Zervou & others, 2000). Such a scenario may occur along the periphery of bonded enamel cavosurface margins or when the adhesive is used as a pit-and-fissure sealant. This hypothesis has to be further substantiated in clinical trials.

The moderately aggressive Xeno III produced a "coral-like" etching pattern (García-Godoy & Gwinnett, 1991) along the surface of aprismatic enamel. The degree of enamel dissolution was even more extensive in Simplicity, and after phosphoric acid-etching with localized, complete dissolution of the aprismatic layer and the creation of type 1 and 2 etching patterns in the exposed prismatic enamel. Apart from these topographical variations, the increasing aggressiveness of these adhesives could also be seen by the difference in thickness of the hybrid layers and the condition of the etched apatite crystallites along the surface of these hybrid layers. Whereas only inter-crystallite monomer infiltration was observed with Clearfil SE Bond and Xeno III, both inter-crystallite and intra-crystallite resin infiltration (Hannig & others, 2002) could be possible in enamel etched with Simplicity and phosphoric acid. The latter mode of resin infiltration is due to the creation of central defects within the cores of the apatite crystallites during acid etching (Jongebloed, Molenaar & Arends, 1975).

The absence of correlation between the depth and pattern of demineralization and strength of bonds produced by the more aggressive self-etch and total-etch adhesives on unground enamel is consistent with previous work (Perdigão & others, 1997; Pashley & Tay, 2001; Ibarra & others, 2002). As composites, adhesives, enamel and dentin were all part of the bond-testing specimens, the failure modes that occurred in these adhesive joints must ultimately be determined by the location of inherent defects in these materials or substrates, so that exclusive failure along the adhesive joints would not be a realistic expectation. Nevertheless, a high percentage of these failure modes were adhesive in nature. For these adhesive failures, the authors speculate that failure occurred via a similar mechanism, as bond strength did not correlate with hybrid layer thickness. It is possible that failure was initiated by the stiffness/toughness mismatch between the hybridized enamel and the natural enamel tissues that was also observed during ultramicrotomy of the TEM specimens. Joint fracture, which occurs via a stiffness/toughness mismatch between dissimilar materials (Jung & others, 1999), is not uncommon. Separation between the more resilient hybridized enamel and more brittle natural enamel may also be seen in the form of subsurface enamel microcracks (white margins) along the enamel cavosurface margins of bonded cavities that have limited capacity to relieve stresses generated during composite polymerization shrinkage (Han, Okamoto & Iwaku, 1992). Unlike the dentinoenamel junction that confers excellent toughness and crack deflecting properties to the joint between enamel and dentin (Marshall & others, 2001), such a structure is lacking in the adhesive-enamel joint. The high surface energy of etched enamel and the hydrophilicity of these adhesives would facilitate optimal wetting and resin infiltration within the etched enamel, so that discrepancies between the depth of etching and depth of resin infiltration should be minimal (Lai & others, 2002). Thus, the stiffness/toughness mismatch between hybridized and natural enamel may provide a plausible explanation for the absence of correlation between the ultrastructural morphology and bond strengths when bonding to unground enamel. This issue warrants further investigation.

CONCLUSIONS

Within the limits of this study, it may be concluded that the microtensile bond strengths of aggressive self-etch adhesives such as Xeno III and Simplicity to unground enamel were not significantly different from total-etch adhesives. Aggressive self-etch adhesives are potentially useful for bonding to unground enamel such as that present in occlusal fissures, in conjunction with the use of pit-and-fissure sealants and for the bonding of orthodontic brackets.

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Post-gel Shrinkage with Different Modes of LED and Halogen Light Curing Units

MS Soh • AUJ Yap • KS Siow

Clinical Relevance

The use of soft-start and pulse activation modes of some curing lights may reduce polymerization shrinkage

SUMMARY

This study compared the post-gel shrinkage of two LED (light-emitting diodes) lights (Elipar FreeLight [FL], 3M ESPE; GC e-Light [EL], GC), a high intensity (Elipar TriLight [TL], 3M ESPE) and a very high intensity (Astralis 10 [AS], Ivoclar Vivadent) halogen light to a conventional (Max [MX] (control), Dentsply-Caulk) halogen light. Ten light curing regimens were investigated. These included continuous (FL1, EL2, MX, TL1 and AS1), soft-start (FL2, EL4, TL2), pulse activation (EL1) and turbo (EL3) modes. A strain-monitoring device and test configuration was used to measure the linear polymerization shrinkage of a composite restorative (Z100, [3M ESPE]) during and post-light polymerization up to 60 minutes when cured with the different modes. Five specimens were made for each cure mode. Results were analyzed using ANOVA/Scheffe's post-hoc test and independent sample *t*-tests at significance level 0.05. Shrinkage associated with the various modes of EL was significantly lower than MX immediately after light polymerization and at one-minute post-light polymerization. No significant difference between MX and the various lights/cure modes was observed at 10, 30 and 60-minutes post-light polymerization. At all time intervals, post-gel shrinkage associated with continuous light curing mode was significantly higher than the soft-start light curing mode for FL and TL.

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INTRODUCTION

Light-activated composites have revolutionized modern restorative dentistry in the mid-1960s and have since undergone developmental improvements in performance characteristics such as esthetics, wear rate and handling (Tolidis, Nobecourt & Randall, 1998). Despite improvements in components and characteristics of composite materials, polymerization shrinkage still remains a clinically significant problem (Carvalho & others, 1996; Davidson & Feilzer, 1997; Yap & others, 2000; Sakaguchi & others, 1991). Dental composites exhibit the inherent problem of 2-4% volumetric shrinkage during polymerization process (Emami, Söderholm

& Berglund, 2003; Price, Rizkalla & Hall, 2000; Feilzer, de Gee & Davidson, 1987). The total shrinkage can be divided into pre-gel and post-gel phases. During pre-gel polymerization, the composite flows, and stresses within the structure are relieved (Davidson & de Gee, 1984). After gelation, flow ceases and cannot compensate for shrinkage stresses. Thus, post-gel polymerization results in significant stresses in the surrounding tooth structure and composite tooth bond (Feilzer & others, 1987). These stresses may produce defects in the composite-tooth bond, leading to bond failure, microleakage, post-operative sensitivity and recurrent caries. Such shrinkage stresses could also cause deformation of the surrounding tooth structure if the composite-tooth bond is good (Sheth, Fuller & Jensen, 1988), predisposing the tooth to fracture.

The effect of post-gel shrinkage and contraction stress can be minimized by clinical techniques such as incremental layering of composite during placement (Kemp-Scholte & Davidson, 1990) and application of low elastic modulus liner between the tooth and contracting composite restorative (Choi, Condon & Ferracane, 2000). A recent method of minimizing polymerization shrinkage without affecting the degree of conversion of light-activated composites is to allow flow during setting by means of controlled polymerization. This can be achieved by applying short pulses of energy (pulse activation) or pre-polymerization at low-intensity light followed by a final cure at high intensity (soft-start techniques). While some studies have shown these polymerization modes result in lower shrinkage, smaller marginal gap, increased marginal integrity and improved material properties (Kanca & Suh, 1999; Uno & Asmussen, 1991; Mehl, Hickel & Kunzelmann, 1997), other studies have found no significant difference in shrinkage when compared to continuous cure modes (Koran & Kürschner, 1998; Price & others, 2000; Silikas, Eliades & Watts, 2000; Yap, Ng & Siow, 2001; Yap, Soh & Siow, 2002).

Despite their popularity, using halogen light curing units (LCUs) to polymerize dental composite has several drawbacks. The halogen bulbs (which have a limited effective lifetime of about 40 to 100 hours), reflector and filter degrade over time due to high operating temperatures and the significant amount of heat produced during the curing cycles (Jandt & others, 2000). The aforementioned will reduce the effectiveness of polymerization in composite restoratives (Barghi, Berry & Hatton, 1994). To overcome such drawbacks of halogen curing light units, blue LED (light-emitting diodes) LCUs have been developed for polymerization of light-activated dental materials. LED have lifetimes of more than 10,000 hours and undergo little degradation of light output overtime. They use junctions of doped semiconductors (p-n junctions) to generate light and, hence, require no filters to produce blue light and are resistant to shock and vibration. Their relatively low power consumption makes them suitable for portable use. The narrower spectral output of these blue LED of 440–490 nm falls within the camphoroquinone (CQ) absorption spectrum (Mills, Jandt & Ashworth, 1999). Previous studies (Mills & others, 1999; Jandt & others, 2000; Stahl & others, 2000) have shown that blue LED LCUs have the potential to polymerize dental composites without having the drawbacks of halogen LCUs. A recent study by Hofmann, Hugo and Klaiber (2002) demonstrated that LED LCUs resulted in a lower polymerization shrinkage strain after 60 minutes when compared to a halogen LCU.

While blue LED LCUs have the potential to reduce polymerization shrinkage, the number of studies on post-gel shrinkage of LED and their various cure modes are still limited. Hence, this study determined and compared the post-gel shrinkage of various curing regimens of two LED lights (Elipar FreeLight [FL], 3M ESPE; GC e-Light [EL], GC), a high intensity (Elipar TriLight [TL], 3M ESPE) and a very high intensity (Astralis 10 [AS], Ivoclar Vivadent) halogen light to a conventional (Max [MX] (control), Dentsply-Caulk) halogen light. For curing lights that offer multiple modes of curing, differences in polymerization shrinkage between soft start/pulse/turbo activation were compared to standard, continuous cure.

METHODS AND MATERIALS

A mini-filled resin composite (Z100; 3M ESPE, St Paul, MN, USA) of A2 shade and five LCUs were selected for this study. Details of the five LCUs and the 10 light curing regimens evaluated are listed in Table 1. A conventional continuous cure halogen LCU (Max) served as the control light source. Intensity of all the curing lights was checked

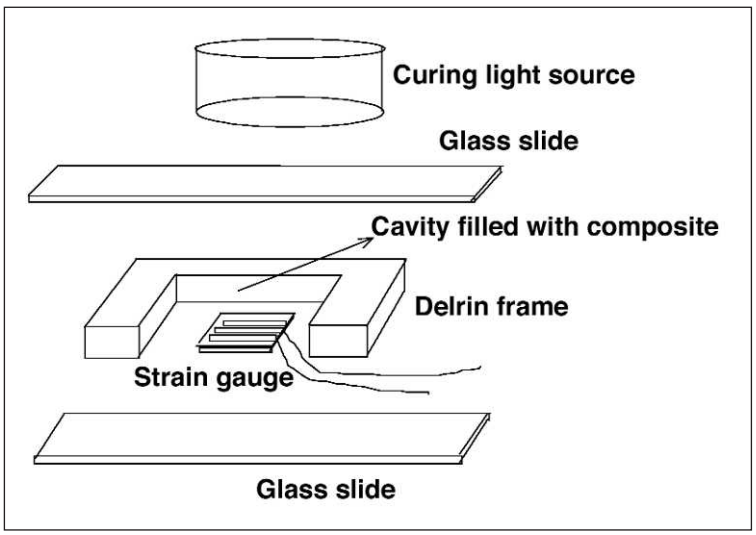

Figure 1. *Diagrammatic representation of the experimental set-up for the assessment of polymerization shrinkage.*

with a radiometer (Cure Rite, EFOS INC, Ontario, Canada) prior to use to ensure consistency in intensity output from the light source. Standard deviations ranging from 2.17 to 5.34 mW/cm^2 were obtained for the various lights.

The experimental set-up for measuring post-gel polymerization shrinkage was based upon that used by Yap and others (2000; 2001; 2002). A diagrammatic representation of the test configuration for measuring polymerization shrinkage is shown in Figure 1. A glass slide served as the base of the set-up and a stiff black delrin frame (inner length 7.0 mm, width 4.0 mm and height 2.0 mm) was used to circumscribe the composite sample with the exception of a window for the strain gauge leads. Foil electrical resistance strain gauges (Foil Strain Gauge, RS Components Ltd, Singapore) were attached to the flat surfaces on the glass slides. The gauges were 2-mm in length and had an electrical resistance 120 Ω and gauge factor 2.00. With the strain gauges in place, the resin composites were placed into the cavity of the delrin frame. Care was taken to ensure complete filling of the frame and excess composite material was extruded using pressure applied through a second glass slide and removed. The surface tack of the composite was adequate to ensure adhesion between the strain gauge and the composite materials. The leads from the strain gauge were connected to a strain-monitoring device (Strain Gauge Recorder, Cole Parmer Instruments, IL, USA) initially balanced at zero. The strain-monitoring device consisted of a chart recorder that functions by rationing sense voltage to signal voltage and converting it to analog output. Dimensional changes are thus effectively transferred to the gauges and measured in terms of resistance.

Table 1: *Details of the Light Curing Units (LCU) and the Various Curing Modes Evaluated*

LCU	Curing Modes	Curing Profiles
Elipar FreeLight	Standard (FL1) (LED)	400 mW/cm^2 (40 seconds)
3M ESPE, Seefeld, Germany	Exponential (FL2)	0-400 mW/cm^2 (12 seconds) → 400 mW/cm^2 (28 seconds)
GC e-Light (LED)	Pulse Curing (EL1)	750 mW/cm^2 (10 pulses x 2 seconds)
GC Europe, Leuven, Belgium	Standard (EL2)	350 mW/cm^2 (40 seconds)
	Turbo (EL3)	600 mW/cm^2 (20 seconds)
	Soft-start curing A (EL4)	0-600 mW/cm^2 (20 seconds) → 600 mW/cm^2 (20 seconds)
Max (Halogen)	Standard (MX)	400 mW/cm^2 (40 seconds)
Dentsply-Caulk, Milford, DE, USA		
Elipar TriLight (Halogen)	Standard (TL1)	800 mW/cm^2 (40 seconds)
3M ESPE, Seefeld, Germany	Exponential (TL2)	100-800 mW/cm^2 (15 seconds) → 800 mW/cm^2 (25 seconds)
Astralis 10 (Halogen)	High Power (AS1)	1200 mW/cm^2 (10 seconds)
Ivoclar-Vivadent, Liechtenstein, Austria		

Curing profiles are based on manufacturers' information.

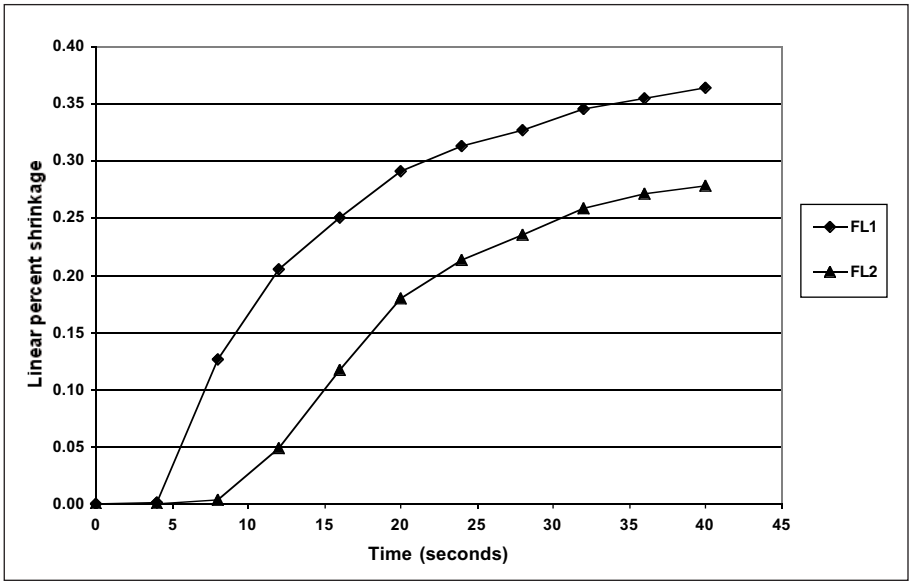

Figure 2. *Mean shrinkage during light polymerization for Epilar Free Light.*

The composite specimens were then light polymerized with the tip guide of the light unit placed on the glass slide above the restorative composite. Five specimens were made for each light-curing regimen. Dimensional change during and post-light polymerization was monitored in air at room temperature (25 ± 1°C). A total of 10 polymerization shrinkage measurements at equal time intervals

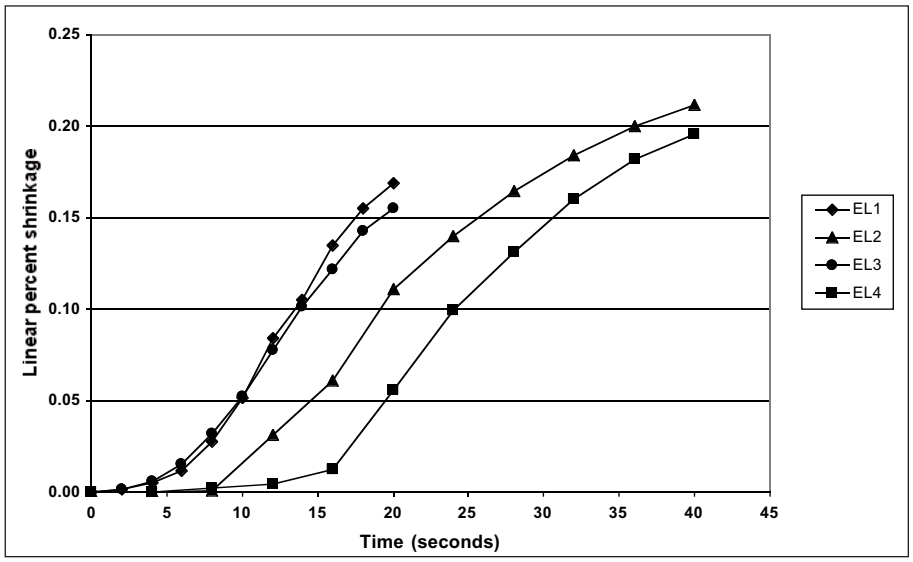

Figure 3. *Mean shrinkage during light polymerization for GC e-Light.*

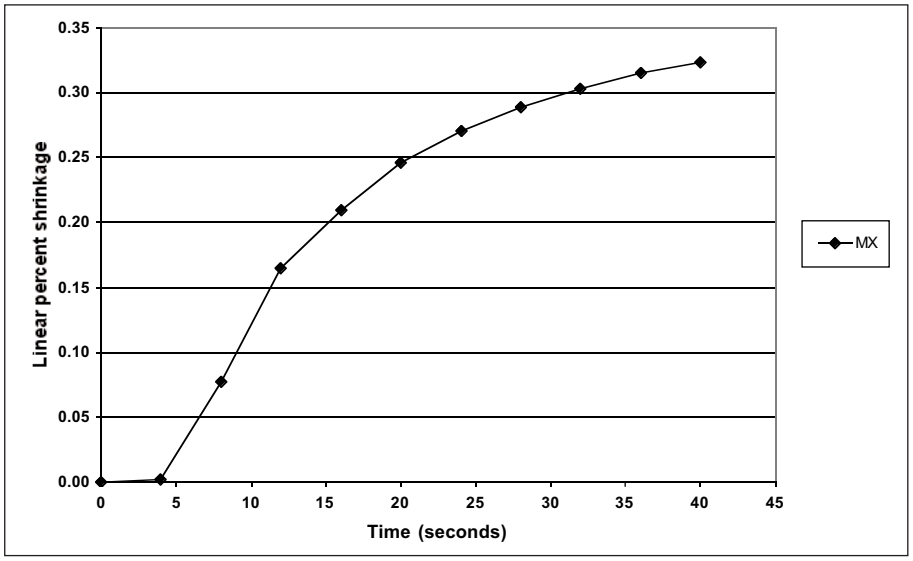

Figure 4. *Mean shrinkage during light polymerization for Max.*

during light polymerization were taken, while post-light polymerization shrinkage measurements were taken at 0 (immediately after light polymerization), 1, 10, 30 and 60 minutes after removal of the curing light. Percentage linear shrinkage was derived from the following equation:

$$\text{Percentage linear shrinkage} = \frac{\Delta L}{L} \times 100 = \frac{\Delta R/R}{K} \times 100$$

where ΔL = Change in length, L = Original length, ΔR = Change of resistance, R = Original resistance and K = Gauge factor (2). Data was subjected to one-way ANOVA and Scheffe's post-hoc tests and independent samples *t*-tests at significance level 0.05.

RESULTS

The mean linear percent shrinkage of the various light curing units and their curing regimens evaluated during light polymerization are shown in Figures 2 through 6. The mean linear percent polymerization shrinkage at the various post-light polymerization time intervals is shown in Table 2 and Figure 7. Results of statistical analysis are shown in Tables 3 and 4.

Post-gel polymerization shrinkage ranking of the various light curing regimens at 0 and 60 minutes were as follows: 0 minute (immediately after light polymerization) – TL1 > AS1 = FL1 > MX > FL2 > TL2 > EL2 > EL4 > EL1 > EL3; and at 60 minutes post-light polymerization - AS1 > TL1 > FL1 > MX > TL2 = FL2 > EL1 > EL4 > EL2 = EL3. At 0 and one minute after light polymerization, post-gel shrinkage of EL1 to EL4 was significantly lower than the control (MX). Post-gel shrinkage of AS1 at one minute after light polymerization was significantly higher than MX. No significant difference in post-gel shrinkage was observed between control and all light curing regimens at 10, 30 and 60 minutes after light polymerization. At all time intervals, post-gel polymerization shrinkage of soft-start light curing modes of FreeLight and TriLight (FL2 and TL2) was found to be significantly lower than their respective continuous light curing modes (FL1 and TL1).

DISCUSSION

The shrinkage behavior of light-activated composite depends on the irradiation temperature (Hofmann & others, 2002), host temperature and environment, irradiation regime and intrinsic factors such as monomer system, concentration of the catalyst, amount of filler and filler type, size and coating (Pananakis & Watts, 2000). Polymerization shrinkage of composite occurs by bond formation between monomers during polymerization. The distance between monomers due to van der waals' forces is transformed into the distance of covalent bonds of the polymer that are formed. Magnitude of shrinkage is determined by the number of covalent bonds formed and the size of monomers (Ferracane, 1995).

Various techniques have been developed to measure the polymerization shrinkage of composites. These

include water and mercury dilatometers (Penn, 1986; Feilzer, de Gee & Davidson, 1988; de Gee, Davidson & Smith, 1981), cuspal deflection (Suliman, Boyer & Lakes, 1994), measuring specific gravity (Puckett & Smith, 1992) and optical measurement of linear shrinkage (Aw & Nicholls, 1997). The experimental setup for measuring post-gel polymerization shrinkage in this study was based upon that used by Yap and others (2000; 2001; 2002), where measurement of linear shrinkage was evaluated by the use of electrical strain gauges. Strain gauges are extremely sensitive to linear dimensional changes. When the gauge is bonded to a substrate, the linear dimensional changes in the substrate are efficiently transferred to the gauge and readily measured. This linear dimensional change is only transferred when the substrate has a measurable modulus (post-gel) to induce stress on the gauge and may therefore be applicable to the measurement of post-gel shrinkage (Sakaguchi & others, 1991). Linear shrinkage measurements are comparable to shrinkage measurements obtained using a mercury dilatometer (de Gee, Feilzer & Davidson, 1993). Both methods continuously measure the free shrinking bulk of materials. The linear shrinkage method is, however, simpler, faster and less laborious than the mercury dilatometer technique.

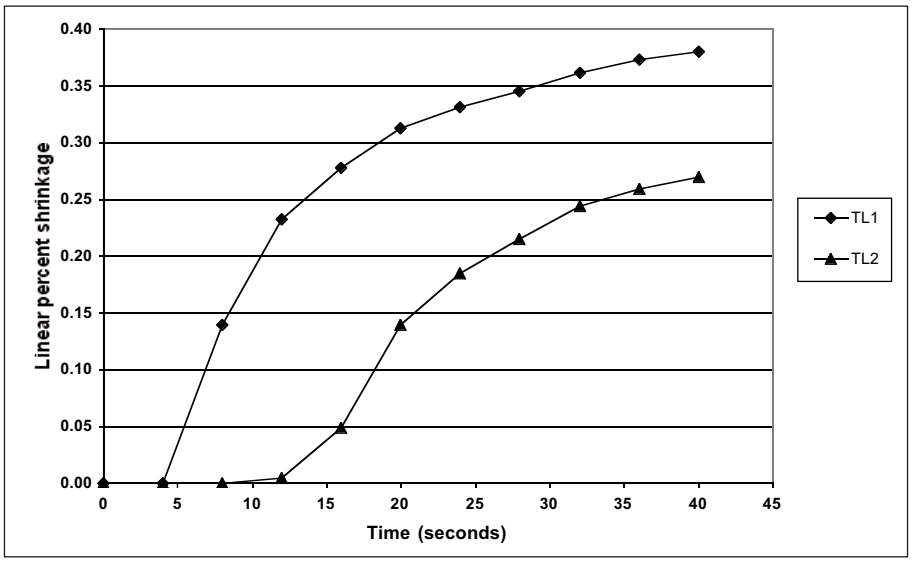

Figure 5. *Mean shrinkage during light polymerization for Epilar TriLight.*

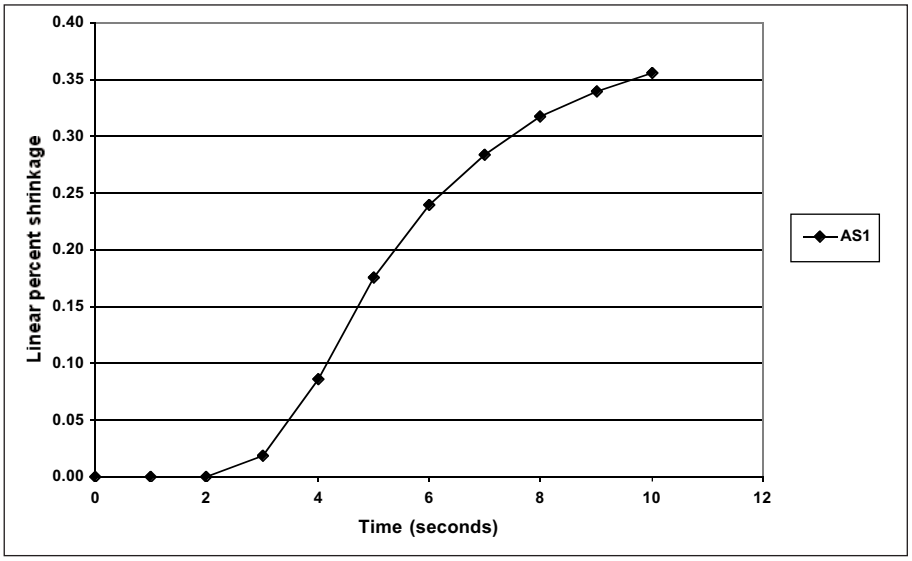

Figure 6. *Mean shrinkage during light polymerization for Astralis 10.*

Z100 was selected for this study, as it exhibited the greatest contraction stress among various composites (Versluis, Sakaguchi & Douglas, 1993). Factors influencing the transmission of light include the thickness of the restorative material, the presence and size of filler particles and the distance of the light tip to the restoration surface (Tate, Porter & Dosch, 1999). As these factors were all standardized in this study, any reduction in polymerization shrinkage may be attributed to the light-curing regimen. Two-mm thick composite specimens were used to ensure uniform and maximum polymerization (Yap, 2000). A2 shade was selected to minimize the effects of colorants on light polymerization (Bayne, Heymann & Swift, 1994). As a minimum intensity of 400 mW/cm^2 has been suggested for routine polymerization (Rueggeberg, Caughman & Curtis, 1994; Tate & others, 1999); this light intensity (Max polymerization unit), together with the manufacturer's recommended cure time of 40 seconds, was used as control in this study.

The rate of shrinkage for all light-curing techniques was greatest during light polymerization reaction and continued after removal of the curing light (Figures 2 to 7). The shrinkage observed after removal of the light source may be attributed to thermal contraction due to loss of radiant heat and the progressive cross-linking reaction in the resin phase of the materials which occurred after light activation (Yap & others, 2000; Sakaguchi & others, 1991). The high shrinkage rate observed during the first minute after cure may be clinically significant. The integrity of the tooth composite interface is rapidly challenged during the early phases

of polymerization when the bond between enamel or dentin and the composite is still maturing (Yap & others, 2000).

AS1 had significantly higher post-gel shrinkage when compared to the control at one minute after light polymerization. This may be attributed to the high intensity employed, which resulted in a high temperature rise during polymerization. In an earlier study, AS1 was found to have the highest irradiation temperature among the light curing modes investigated (Yap & Soh, 2003). The temperature rise during polymerization and heating from radiation of LED LCUs was significantly lower than halogen LCUs. The results corroborated that of Hofmann and others (2002), where the temperature rise observed with halogen light irradiation was higher than with LED. It was also speculated that the high radiation heat produced by AS1 results in an additional acceleration of the polymerization reaction and consequently produces a faster increase in contraction strain. Polymerization with high intensity light sources has been related to increased depth of cure and improved mechanical properties. However, high intensity light sources have also been related to high polymerization shrinkage stresses (Uno & Asmussen, 1991; Feilzer & others, 1995).

All curing modes of EL were found to be significantly lower at 0 and 1 minute after polymerization when compared to the control. This may be due to lower rates of polymerization and lower emission temperature arising from the low irradiance and light energy density employed for the various curing modes. An earlier study (Soh, Yap & Siow, 2003) conducted on EL showed that the effectiveness of cure for all curing modes of EL was inferior when compared to the Max curing units.

No significant difference between MX and various cure modes was observed at 10, 30 and 60 minutes post-light polymerization. The polymerization velocity of composites affects the magnitude of internal stresses (Cehreli & Canay, 2002) and irradiation energy affects the speed of conversion (Davidson-Kaban & others, 1997). Lower irradiation energy slows down the rate of conversion. Asmussen and Peutzfeldt (2001) have pointed out that a slow start polymerization may be associated with few centers of polymer growth, while a high-intensity in the initial phase of the irradiation period will initiate a multitude of growth centers. However, ultimate conversion of the various light curing regimens was achieved despite the varying irradiation energy and rate of conversion. When total irradiation dose was sufficient to completely polymerize the specimens, total shrinkage was essentially independent of the various light-curing intensities used during the curing process (Koran & Kürschner, 1998). This was corroborated by the findings in this study, where no significant difference in post-gel shrinkage was observed between the control and all light curing regimens at 10, 30 and 60 minutes after light polymerization.

When different modes of EL were compared, polymerization shrinkage of EL2 was found to be higher than EL3 immediately after light

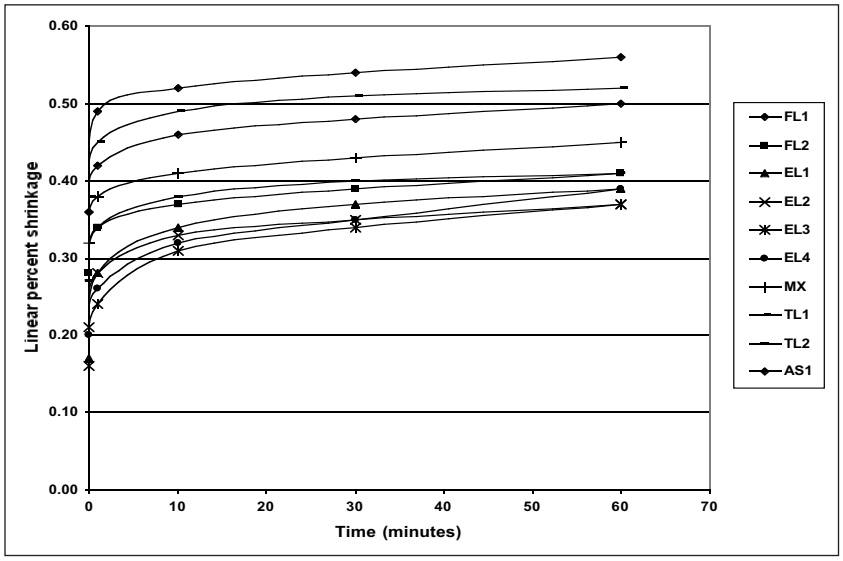

Figure 7. *Mean shrinkage post light polymerization.*

Table 2: *Mean Linear Percent Polymerization Shrinkage at the Various Post-light Polymerization Time Intervals*

Light Curing Modes	0 Minute	1 Minute	10 Minutes	30 Minutes	60 Minutes
FL1	0.36 (0.02)	0.42 (0.02)	0.46 (0.02)	0.48 (0.02)	0.50 (0.03)
FL2	0.28 (0.02)	0.34 (0.03)	0.37 (0.04)	0.39 (0.04)	0.41 (0.04)
EL1	0.17 (0.01)	0.28 (0.03)	0.34 (0.02)	0.37 (0.02)	0.39 (0.02)
EL2	0.21 (0.03)	0.28 (0.03)	0.33 (0.04)	0.35 (0.04)	0.37 (0.05)
EL3	0.16 (0.02)	0.24 (0.03)	0.31 (0.04)	0.34 (0.05)	0.37 (0.06)
EL4	0.20 (0.03)	0.26 (0.03)	0.32 (0.04)	0.35 (0.04)	0.39 (0.03)
MX	0.32 (0.04)	0.38 (0.04)	0.41 (0.05)	0.43 (0.04)	0.45 (0.05)
TL1	0.38 (0.04)	0.45 (0.05)	0.49 (0.06)	0.51 (0.06)	0.52 (0.07)
TL2	0.27 (0.03)	0.34 (0.04)	0.38 (0.04)	0.40 (0.05)	0.41 (0.05)
AS1	0.36 (0.04)	0.49 (0.04)	0.52 (0.05)	0.54 (0.04)	0.56 (0.04)

Standard deviations in parentheses.

Table 3: *Results of Statistical Analysis*

Time	Differences
0 minute	EL1, EL2, EL3, EL4 < MX
1 minute	EL1, EL2, EL3, EL4 < MX < AS1
10 minutes	NS
30 minutes	NS
60 minutes	NS

< denotes statistically significant differences. Results of one-way ANOVA/Scheffe's post-hoc test (p<0.05). NS denotes no statistical significance.

Table 4: *Comparison of Polymerization Shrinkage Between Curing Modes for LCU That Offer Different Polymerization Regimens*

Time	LCU	Differences
0 minute	Elipar FreeLight	FL2 < FL1
	GC e-Light	EL3 < EL2
	Elipar TriLight	TL2 < TL1
1 minute	Elipar FreeLight	FL2 < FL1
	GC e-Light	NS
	Elipar TriLight	TL2 < TL1
10 minutes	Elipar FreeLight	FL2 < FL1
	GC e-Light	NS
	Elipar TriLight	TL2 < TL1
30 minutes	Elipar FreeLight	FL2 < FL1
	GC e-Light	NS
	Elipar TriLight	TL2 < TL1
60 minutes	Elipar FreeLight	FL2 < FL1
	GC e-Light	NS
	Elipar TriLight	TL2 < TL1

Results of one-way ANOVA/Scheffe's post-hoc test or Independent Samples t-test (p<0.05). < indicates statistical significance, while NS denotes no statistical significance.

polymerization. The rate of polymerization with EL2 may be faster than EL3 due to the higher light energy density employed by EL2. No significant difference was observed between pulse activation (EL1) and continuous (EL2) mode. At all time intervals, post-gel shrinkage associated with continuous cure was found to be significantly higher than the soft-start curing mode for FL and TL. Soft-start polymerization, which employs different intensity distribution during polymerization, allows higher material flow which reduces contraction stresses in the cavity during polymerization and preserves marginal integrity (Price & others, 2000). Soft-start curing regimens may also reduce the likelihood of pulp damage caused by excessive heat generated by the light-curing units. In an earlier study (Yap & Soh, 2003), the thermal emission produced by soft-start curing modes was found to be significantly lower than continuous curing modes. With an adequate total irradiation dose, the properties of resin composite cured with soft-start polymerization were as good as or better than those obtained using conventional continuous curing method.

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. Post-gel shrinkage immediately after light polymerization ranged from 0.16 % to 0.36 % for LED LCUs.
2. Post-gel shrinkage immediately after light polymerization ranged from 0.27 % to 0.38 % for halogen LCUs.
3. At 10, 30 and 60 minutes after light polymerization, no significant difference in post-gel shrinkage were observed between control and all light curing regimens.
4. For Freelight and TriLight, curing with exponential mode resulted in significantly lower shrinkage than the standard continuous mode.

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Temperature Rise During Adhesive and Resin Composite Polymerization with Various Light Curing Sources

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Clinical Relevance

Clinicians should be aware of the potential thermal hazard to dental pulp that can arise in the restoration of deep cavities during photopolymerization of adhesive resin materials with light sources.

SUMMARY

This study evaluated the temperature rise in two different adhesive (Clearfil SE Bond [CSEB] and EBS-Multi [EBSM]) and composite systems (Clearfil AP-X [CAPX,] Pertac II [PII]) by the same manufacturer when illuminated by four different light sources: Light-emitting diode (LED), Plasma arc curing (PAC), high intensity quartz tungsten halogen (HQTH) and quartz tungsten halogen (QTH). Forty dentin disks were prepared from extracted premolars. These dentin disks were placed in apparatus developed to measure temperature rise. Temperature rise during photopolymerization of adhesive resin and resin composite was then measured. The mean values of temperature increases for adhesive and resin composites did not differ significantly (p=0.769). The highest temperature rise was observed during photopolymerization of EBSM with PAC (5.16°C) and HQTH (4.28°C), respectively. Temperature rise values produced by QTH (1.27°C – 2.83°C for adhesive resin; 1.86°C – 2.85°C for resin composite) for both adhesive and resin composites were significantly lower than those induced by PAC and HQTH (p<0.05). However, these values were significantly higher than those produced by LED (1.16°C – 2.08°C for adhesive resin; 1.13°C – 2.59°C for resin composite). Light sources with high energy output (PAC and HQTH) caused significantly higher temperature rise than sources with low energy output (QTH and LED). However, in this study, no temperature rises beneath 1-mm dentin disk exceed the critical 5.6°C value for pulpal health.

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INTRODUCTION

For many years, the possibly of the damaging effects of temperature increases on pulp tissue during restorative treatment has concerned dentistry (Hannig & Bott, 1999). Cavity preparation, polymerization of lining and

restorative materials with or without the use of light-curing systems all serve as potential sources of temperature rise at the cavity floor and, as such, must be regarded as having the ability to produce an increase in intrapulpal temperature (Smail & others, 1988).

Zach and Cohen (1965), using monkey teeth, showed that with their chosen experimental technique, a rise of 5.6°C in pulp, caused considerable damage, resulting in complete loss of vitality in 15% of teeth. The thickness of dentin between the floor of a cavity and the pulp chamber influences the rise in temperature of material placed in that cavity (Smail & others, 1988). Meredith and others (1984) pointed out that the situation *in vivo*, where there is movement of blood or other fluids with the consequential potential for heat dissipation, is different from *in vitro* experiments using extracted teeth. Even a small rise in pulpal temperature, irrespective of its method of induction, seems to produce histological evidence of pulpitis of varying severity in animals. *In vitro* experiments can, however, also yield results that serve to alert clinicians to a potential hazard to the health of pulp (Smail & others, 1988).

Temperature rise during the curing of light activated restoratives relates to both the exothermic polymerization of the material and the heat output from dental light curing units and expands with increasing radiation time and decreased material thickness (Lloyd, Joshi & McGlynn, 1986). Temperature increases of up to 20°C or more have been measured within resin composite during light-induced polymerization (McCabe, 1985; Lloyd & others, 1986; Masutani & others, 1988). Previous *in vitro* studies have shown that light polymerization of resin composite or subjecting the surface of teeth to conventional light curing causes the intrapulpal temperature to increase only a few degrees due to thermal insulation of dental hard tissue. However, the increased power of commercially available dental light curing units has also increased the potential for generating unacceptable temperatures in pulp tissue (Hannig & Bott, 1999). When Castelnuovo and Tjan (1997) measured the temperature rise in pulp during the fabrication of provisional resin crowns, the results demonstrated that the amount of heat generated during resin polymerization and transmitted to the pulpal chamber could be damaging to pulpal tissues, including odontoblasts. Hartanto, Van Benthem and Ott (1990) also pointed out the possibility of high temperatures observed in the polymerization of most composites and their adverse effects on pulp tissue.

The most widely used light source for photoactivating resin-based composite is quartz tungsten halogen (QTH) lights (Hofmann, Hugo & Klaiber, 2002). However, heat generation is a major disadvantage to using QTH as a light source (Fujibayashi & others, 1998). Quartz tungsten halogens with higher light intensities (HQTH) hold significant potential for use in dentistry. Decreasing total cure time for adhesive and composite materials is apparently beneficial for the clinician and patient. In addition, higher curing light intensities may lead to superior physical and mechanical properties (Ruyter & Oysaed, 1988; Rueggeberg, Caughman & Curtis, 1994). The plasma arc curing (PAC) light is also designed for the high-speed curing of composite filling materials in direct resin restorations. A high energy, high pressure ionized gas in the presence of an electrical current is used to create a high temperature light source strong enough to increase the curing rate of resin composites. As the manufacturer (ADT, San Carlos, CA, USA) stated, highly filled and pigmented composite materials can be cured in 10 seconds, while more transparent materials can be cured within five seconds. This rapid curing feature saves considerable chairside time when compared with QTH. However, these units sell at several times the price of QTH lights. Concerns have been raised regarding radiation heating created by the high light intensity and negative side-effects of rapid polymerization shrinkage, which may compromise the marginal seal of restorations (Brackett, Haisch & Covey, 2000; Oesterle, Newman & Shellhart, 2001; Hofmann & others, 2002; Park, Krejci & Lutz, 2002).

Light-emitting diodes (LED) feature very narrow spectral ranges and are therefore highly efficient light sources (Hofmann & others, 2002). The high efficiency of LED allows the development of battery-powered cordless lights and eliminates the need for cooling fans (Hofmann & others, 2002). The narrow bandwidth of emitted radiation (Jandt & others, 2000) should be optimally suited for activating camphoroquinone, but alternative photo-initiators absorbing at shorter wavelengths will most likely not be sufficiently activated. Heating of irradiated objects by LED lights is expected to be minimal (Hofmann & others, 2002; Tarle & others, 2002).

This study evaluated the temperature rise in two different adhesive and composite systems by the same manufacturer when illuminated by four different light sources: LED, PAC, HQTH and QTH.

METHODS AND MATERIALS

Two different adhesive systems and hybrid composites were used for temperature rise measurements. Table 1 features the materials, manufacturers and other relevant information.

Four different light sources were evaluated in this study (Table 2). The output of light tips from QTH (Hilux), HQTH (Optilux) and LED (Elipar Freelight) curing units was measured using a digital curing radiometer (Curing radiometer, Demetron, Danbury, CT, USA) (Table 2). Output of the PAC (Power PAC) system, which could not be measured by cure radiome-

Table 1: *Adhesive Systems and Application Procedures Recommended by the Manufacturers*

Materials	Procedures	Manufacturer
CSEB +Clearfil AP-X	Apply primer 20 seconds, air dry gently, apply adhesive resin, light cure (10 seconds with QTH, HQTH and LED; 5 seconds with PAC), apply Clearfil AP-X (B2) in 2-mm thickness, light cure (40 seconds with QTH,HQTH and LED; 10 seconds with PAC)	Kuraray, Osaka, Japan
EBSM + Pertac II	Acid-etching; apply 20 seconds, 15 seconds rinse and air dry gently, apply primer,air dry, apply adhesive resin, light cure (20 seconds with QTH,HQTH and LED; 7 seconds with PAC), apply Pertac II (B2) in 2-mm thickness, light cure (40 seconds with QTH,HQTH and LED; 10 seconds with PAC)	ESPE, Seefeld, Germany

Table 2: *Light Sources Used in This Study*

Materials Brand	Power Density	Diameter of the Tip (mm)	Manufacturer
Hilux	500 mW/cm^2	10	Express Dental Products, Toronto, Canada
Optilux 501	850 mW/cm^2	8	Kerr, Danbury, CT, USA
Power PAC	1200-1500 mW/cm^2	6.5	ADT, San Carlos, CA, USA
Elipar Freelight	400 mW/cm^2	8	3M ESPE, St Paul, MN, USA

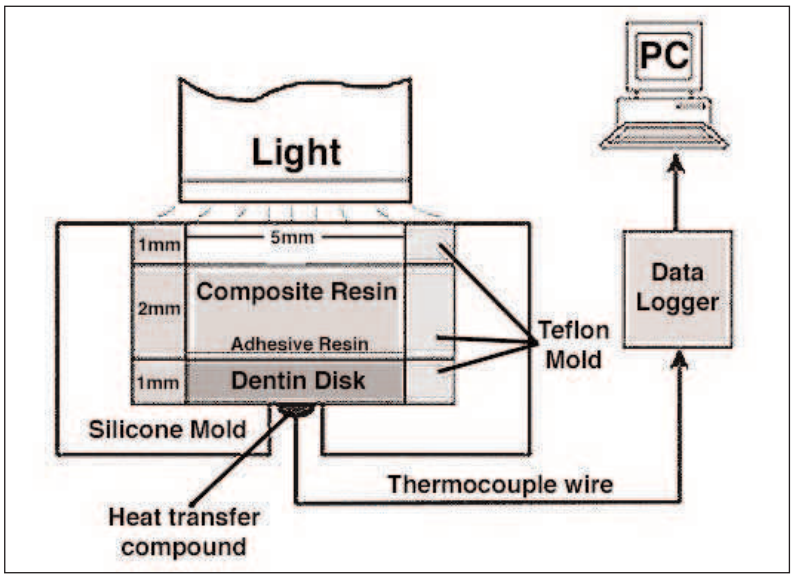

Figure 1. *Schematic drawing of temperature measuring apparatus.*

ter, was 1200-1500 mW/cm^2 according to the manufacturer's instructions.

Figure 1 shows the apparatus used to measure temperature rises, which was modified from that developed by Smail and others (1988) for temperature rise measurement. It comprises three concentric Teflon mold cylinders constructed from polytetrafluoroethylene. The top Teflon mold cylinder has a central aperture (5-mm in diameter, 1-mm deep) and locates the aperture exactly over the test specimen. The light tip of the curing unit was centered on this Teflon mold without any distance. Thus, the distance between the light tip of the curing unit and test well was standardized. The central Teflon mold cylinder forms the lateral walls of the test well (5-mm in diameter, 2-mm deep). The bottom Teflon mold cylinder forms the lateral walls of dentin disks (5-mm in diameter, 1-mm deep). With the exception of the upper surface, the entire apparatus was surrounded by a silicon mold. A hole was drilled through the silicon mold to provide entrance for a J-type thermocouple wire (Omega Engineering, Inc, Stamford, CT, USA) just beneath the center region of the dentin disk. A silicone heat-transfer compound (ILC P/N 213414, Wakefield Engineering, Pelham, HH, USA) was applied under dentin disk (Figure 1). This compound facilitated the transfer of heat from the wall of the dentin disk to the thermocouple wire.

Forty extracted human premolars were stored in physiologic saline in an incubator. The occlusal enamel portions of the premolars were removed using a low-speed saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA) to expose the dentin by sectioning the tooth perpendicular to its long axis. Then, dentin disks 1-mm thick were sectioned perpendicular to the long axis of the tooth. Thus, 40 dentin disks were obtained. These dentin disks were placed in the bottom of the Teflon mold cylinder.

Temperature changes were measured at the following three levels:

1. Temperature rise beneath the dentin disk without any restoration to detect whether histochemical and/or structural variables of the dentin disk affect temperature change. Temperature rises beneath all dentin disks were realized by using QTH for 10 seconds. The mean temperature rise was

Table 3: *Mean Values and Standard Deviations of Temperature Rise in Adhesive and Resin Composite Polymerized QTH, HQTH, PAC and LED*

Materials Brand	Hilux (°C) (Mean±SD)	Optilux 501 (°C) (Mean±SD)	Power PAC(°C) (Mean±SD)	Elipar Freeight(°C) (Mean±SD)
CSEB	1.54±0.26	3.32±0.43	2.46±0.26	1.15±0.20
EBSM	3.17±0.33	3.79±0.31	4.55±0.46	1.61±0.36
CAPX	2.22±0.36	3.35±0.24	2.89±0.32	1.88±0.31
PII	2.64±0.28	3.33±0.37	3.47±0.17	2.15±0.31

2.5±0.02°C. Thus, it was concluded that the temperature change was not affected by any histochemical and/or structural dentin variables.

2. Temperature rise during polymerization of the visible light cured adhesive system. After acid etching (for only EBSM), primer (CSEB or EBSM) was applied on the outside of the dentin disks. These dentin disks were placed in the bottom Teflon mold cylinder. Adhesive resin (CSEB or EBSM) was then applied to the disks and the temperature rise was measured during photopolymerization before placing the resin composite according to the manufacturer's instructions (Table 1).
3. Temperature rise during polymerization of the resin composite. To measure the temperature rise produced when the composite materials were cured, the central cylinder aperture was filled with selected materials and each composite material was light cured following the manufacturer's instructions (Table 1).

A J-type thermocouple wire was connected to a data logger (XR440-M Pocket Logger, Pace Scientific, NC, USA) during adhesive and resin composite photopolymerization (Figure 1). Calibration of the data logger was not required. Accuracy specifications were maintained without user adjustment. The temperature accuracy reported by the manufacturer was ± 0.15°C from 0° to 40°C. The collected data were monitored in real time and transferred to a computer. The data were available in both tabular and graphic form. Temperature changes were recorded every two seconds until returning to original temperature.

Differences between the adhesive and resin composite temperature rises were assessed using paired samples *t*-test. Statistically significant differences between the adhesive or resin composite temperature rises were assessed using independent samples *t*-test. Intercepts between adhesive or resin composite temperature rises and light sources were analyzed with two-way ANOVA. Multiple comparisons (light sources) were made using one-way ANOVA and Tukey HSD test. All statistical analysis was carried out using the SigmaStat software system (SPSS/PC, Vers 10.0, SPSS, Chicago, IL USA). Statistical significance was considered as $p<0.05$.

RESULTS

Table 3 and Figure 2 show mean values and standard deviations of temperature increases in adhesive and resin composites polymerized by different light sources. Paired sample *t*-tests did not indicate statistically significant differences between mean temperature rises when adhesive and resin composites were used ($p=0.769$). However, the highest temperature rises were observed during photopolymerization of EBSM adhesive resin with PAC curing (5.16°C) followed by PII resin composite with HQTH curing (3.83°C). Independent sample *t*-tests revealed that temperature rise with EBSM during curing was significantly higher than CSEB ($p=0.001$). However, there were no statistically significant differences between PII and CAPX resin composites ($p=0.051$). Two-way ANOVA revealed significant interaction between the light sources and adhesive resin ($p=0.000$) or between the light sources and resin composite ($p=0.000$). One way ANOVA revealed significant differences in mean temperature rise values produced by different light sources for both adhesives and resin composites ($p=0.000$).

In all specimens, during photopolymerization, the temperature just beneath the dentin disks started increasing immediately and continuously after light contact. The highest temperature rises for both adhesive and resin composite were observed during photopolymerization with PAC (2.12°C - 5.16°C for adhesive resins; 2.16°C - 3.75°C for resin composites) and HQTH (2.82°C - 4.28°C for adhesive resins; 2.99°C -3.83°C for resin composites) (Figures 3 and 4, respectively). The temperature rise values induced by QTH (1.27°C - 2.83°C for adhesive resin; 1.86°C - 2.85°C for resin composite) for both adhesive and resin composite were significantly lower than those induced by PAC and HQTH ($p<0.05$) (Figure 5). However, increases induced by QTH were significantly higher than those induced by LED (1.16°C - 2.08°C for adhesive resin; 1.13°C - 2.59°C for resin composite) (Figure 6).

DISCUSSION

This *in vitro* study measured the temperature rises under dentin disks during polymerization of two adhesive systems by four different commercially available light sources. Data indicated the presence of statistically significant differences between both light sources and adhesive systems ($p<0.05$). In all light sources, temperature rises in EBSM were significantly higher than CSEB. However, there were no statistically significant differences between CAPX and PII. This may result

from using the same irradiation time for all composites, while adhesive resins were subjected to different curing times as recommended by the manufacturers. Knezevic and others (2002) reported higher temperature increases with increased irradiation time and decreased material thickness. On the other hand, for both adhesive and resin composite, PAC (Power PAC) and HQTH (Optilux 501) produced the highest temperature rises, whereas, LED (Elipar Freelight) induced the lowest temperature rise. QTH (Hilux) showed a temperature rise lower than PAC and HQTH, yet higher than LED.

The decisive factor for temperature rise during light activated polymerization of resin composites is the energy absorbed during irradiation, whereas, the exothermic composite polymerization process is of secondary importance for temperature rise (Lloyd & others, 1986). With increased light intensity, an increase in temperature rise because of radiation energy from the light activation unit may occur. The distance between the cavity floor and light guide may vary considerably when curing large posterior resin restorations (Hansen & Asmussen, 1993). Smail and others (1988) and Tjan and Dunn (1988) emphasized that the thickness of the dentin barrier is a critical factor in reducing thermal transfer to pulp. In this study, a critical thickness of 1 mm was used for dentin discs.

Masutani and others (1988) reported that the speed of the exothermic reaction of visible light activated resin composites increase with an increasing intensity of the light source. These authors also concluded that the resin itself had a greater influence on curing than the light source. However, the most significant source of heat during polymerization of a light activated restorative is from the light activation unit and not the material itself (Masutani & others, 1988; Shortall & Harrington, 1998; Knezevic & others, 2002).

Power PAC (1200 mW/cm^2) and Optilux 501 (850 mW/cm^2) curing units are characterized by a higher energy output than Hilux (500 mW/cm^2) and Elipar Freelight (400 mW/cm^2). Therefore, it is reasonable that Power PAC and Optilux 501 curing units produce temperature rises greater than Hilux and Elipar Freelight.

Zach and Cohen (1965) reported irreversible pulpal damage in 15% of rhesus monkeys for temperature elevations of 5.6°C, 60% for temperature elevations of 11°C and 100% for temperature elevations of 16.6°C. In their study, Pohto and Scheinin (1958) also indicated increased capillary permeability, that is, a first sign of heat related pulp damage when the temperature increased 5.5°C and 7°C. Even though their experimental setting was different from this study, their results can be suggested as a baseline for potential

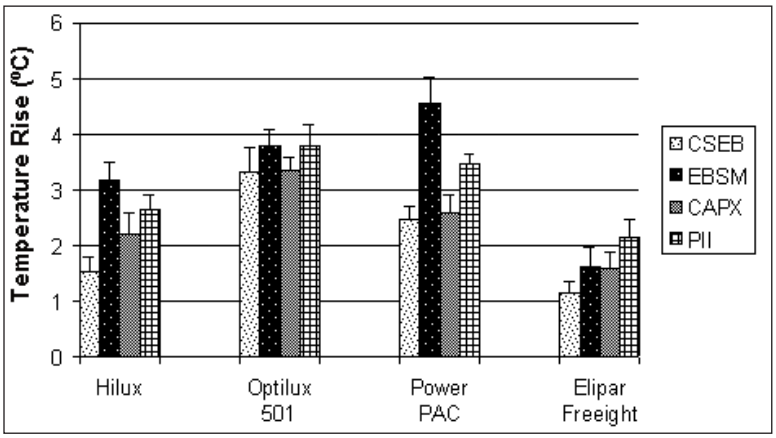

Figure 2. *Temperature rise in adhesive and resin composite polymerized with QTH, HQTH, PAC and LED.*

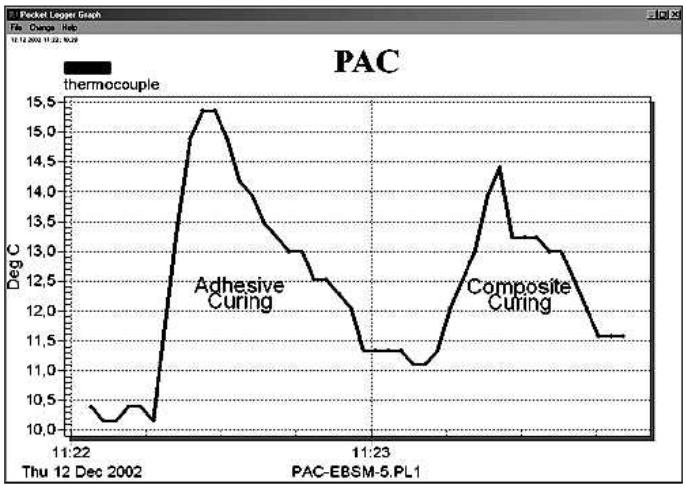

Figure 3. *A representative graphic of a sample that shows temperature rise during EBSM and Pertac II polymerization with PAC (EBSM, 5.16°C; Pertac II, 3.32°C).*

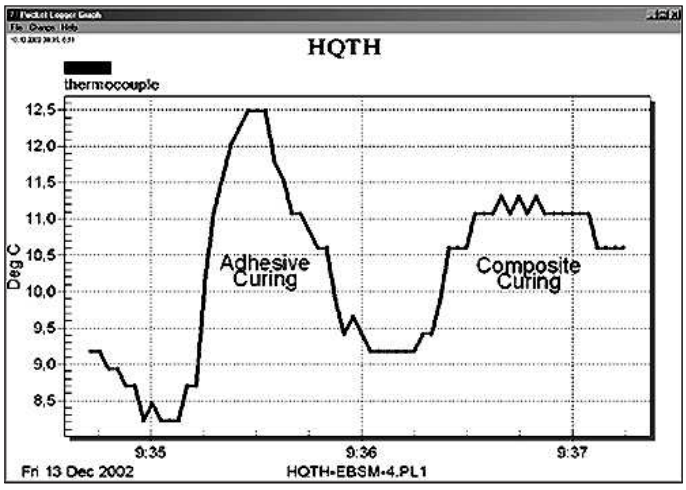

Figure 4. *A representative graphic of a sample that shows temperature rise during EBSM and Pertac II polymerization with HQTH (EBSM, 4.24°C; Pertac II, 2.17°C).*

histopathological changes in pulpal tissues when the temperature rise exceeds 5.6°C. In this study, the maximum temperature rise was induced by Power PAC system (5.16°C, Figure 3). This value was within the limits of pulpal physiology.

Hannig and Bott (1999) prepared Class II cavities in extracted molars, leaving a 1-mm thick dentin layer between the pulp chamber and proximal cavity wall. Thickness of the resin composite was 2 mm in the proximal box. They also found that temperature elevations in the pulpal chamber were as follows: for QTH; Heliolux (320mW/cm^2) 2.9°C, QHL 75 (505 mW/cm^2) 5.6°C and Astralis 5 (515 mW/cm^2) 4.7°C, for HQTH; Elipar Highlight 6.9°C (730 mW/cm^2) and Optilux 500 (670 mW/cm^2) 7.3°C, for PAC; ADT 1000 PAC (1196 mW/cm^2) 7.8°C (10 seconds). They commented that in spite of the energy output from dental light curing units, the very short-term temperature peak may not be relevant to pulpal damage, because the temperature values measured in this study cannot be directly applied to temperature changes *in vivo*. These findings are marginally higher than those of the current study. This, presumably, is a result of differences in methodology.

PAC units have demonstrated markedly reduced curing times: exposures of six to nine seconds produce higher bond strengths and surface hardness values equal to those produced with 40-second exposures of a conventional tungsten-quartz halogen light (Fujibayashi & others, 1998). LED have certain other advantages over both halogen and plasma arc curing lights: they are cordless, smaller, lighter, do not require a noisy cooling fan and have estimated lifetimes of more than 10,000 hours (Olsen & others, 1997). Moreover, LED technology is still developing and high intensity LED-curing lights are on the way. According to Dunn and Taloumis (2002), halogen-based light-curing units might be replaced by LED as semiconductor technology improves (Stahl & others, 2000).

No statistically significant differences were found between the mean temperature rise values of adhesive (2.70°C) and resin composites (2.67°C) used in this study ($p<0.05$). However, it should be noted that the maximum temperature rise of adhesive resin was 5.16°C, while the temperature rise of resin composite was only 3.83°C. These results indicate that the risk for heat induced pulpal damage should be taken into consideration during photo-polymerization of adhesive resins rather than resin composite. However, in clinical conditions, the rises in temperature are reduced by blood circulation in the pulp chamber and fluid motion in the dentinal tubules (Meredith & others, 1984). In addition, the surrounding periodontal tissues can promote heat convection *in vivo*, limiting the intrapulpal temperature rise (Hannig & Bott, 1999).

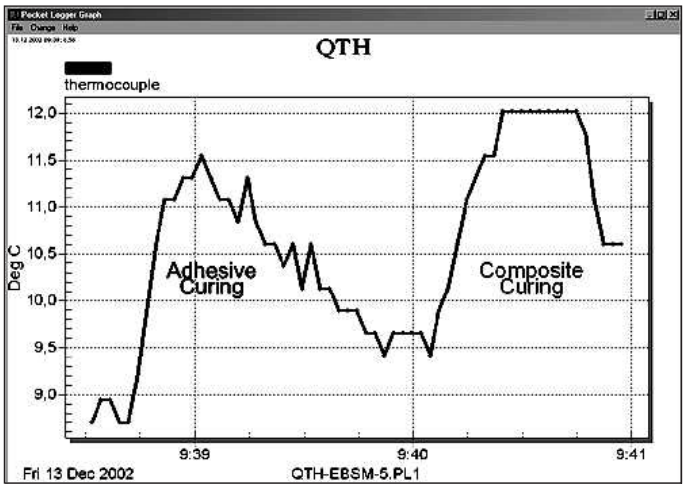

Figure 5. *A representative graphic of a sample that shows temperature rise during EBSM and Pertac II polymerization with QTH (EBSM, 2.83°C; Pertac II, 2.58°C).*

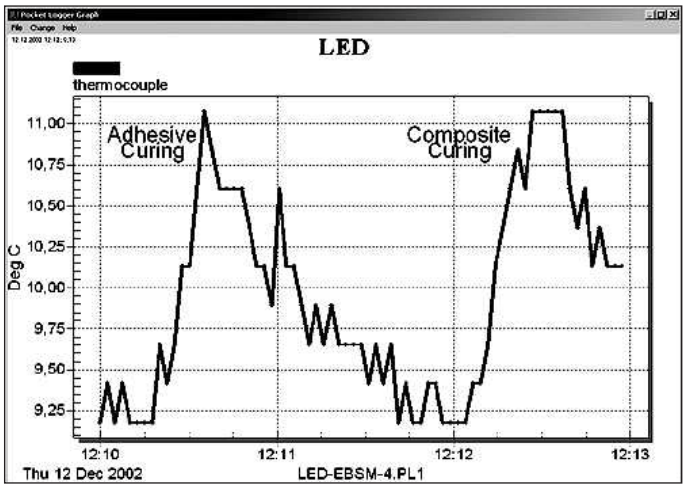

Figure 6. *A representative graphic of a sample that shows temperature rise during EBSM and Pertac II polymerization with LED (EBSM, 1.87°C; Pertac II, 1.82°C).*

However, clinicians should be aware of the potential hazard to the health of pulp that might result from visible light curing of adhesive and resin composites in deep cavities (Smail & others, 1988; Hannig & Bott, 1999). A simple, yet highly effective way to protect pulp is to apply a cement base or lining material (Hansen & Asmussen, 1993). Smail and others (1988) reported that even a thin layer of lining material contributed to the reduction of thermal transfer to pulp. Hansen and Asmussen (1993) found that a 2-mm thick insulation layer of glass ionomer significantly reduces the intrapulpal temperature increase during resin composite polymerization. In addition, adhesive resin may contribute to the protective thermal insulation for the underlying dentin and pulp tissue during resin composite polymerization.

Currently, most clinicians do not accept the use of setting calcium hydroxide cements as linings beneath composites, even if the cavity floor is thought to be close to the pulp (Heitmann & Unterbrink, 1995; Kitasako, Inokoshi & Tagami, 1999; Hebling, Giro & Costa, 1999; Costa, Hebling & Hanks, 2000). In such situations, rises in temperature caused by the photo-polymerization of adhesive resin placed in the cavity or heat transmitted from a curing light are more likely to adversely affect pulp (Smail & others, 1988).

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. Light sources with high energy output (PAC and HQTH) showed a significantly higher temperature rise than low energy output lights (QTH and LED). However, in this study, temperature rises beneath the 1-mm dentin disk that exceeded the critical 5.6°C value for pulpal health were not recorded.
2. The risk for heat induced pulpal damage should be taken into consideration during photopolymerization of adhesive resins in deep cavities in which dentin thickness is lower than 1 mm.

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The Bond of Resin to Different Dentin Surface Characteristics

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Clinical Relevance

The differences in detailed characteristics of dentin surface contribute to the non-uniform adhesion of resin to different areas within any one-cavity preparation.

SUMMARY

This study investigated the effects of dentin surface characteristics on bond strengths between resin and dentin. The shear bond strengths mediated by two dentin adhesive systems (Clearfil SE Bond and OptiBond Solo Plus) were evaluated. For each material, flat dentin surfaces prepared from human upper premolars were allocated to eight groups according to three characterizations; dentin location (occlusal or cervical), dentin depth (superficial or deep) and dentinal tubule orientation (perpendicular or parallel). A 0.75-mm diameter area of dentin was bonded according to each manufacturer's instructions before placing 0.5-mm high resin composite. The bonds were stressed in shear at a crosshead speed of 1 mm/minute. The mean bond strengths were compared using ANOVA and independent *t*-test. No statistically significant differences were found in shear bond strengths based on dentin location. Clearfil SE Bond presented higher bond strengths to deep dentin specimens bonded perpendicular to the tubules compared to those that were bonded parallel to the tubules. Whereas, the opposite results were found for deep dentin specimens bonded with OptiBond Solo Plus. In the case of superficial dentin, there were no differences between the two materials when bond strengths were compared among the different orientations of tubule. The results indicated that shear bond strengths may be affected by dentin depth, orientation of the tubule and the bonding material used, but not by location of the dentin.

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INTRODUCTION

Dentin bonding materials have significantly improved in recent years. The basis of these materials is to effectively adhere to the structure of dentin and a restorative material. Achieving a strong bond between adhesive resin and resin composite is chemical in nature. On the other hand, achieving such a bond between adhesive resin and dentin relies upon the ability of the adhesive resin to penetrate into the conditioned dentin surface (Nakabayashi, Kojima & Masuhara, 1982). This

success depends on many factors that have been continuously reported by many adhesive studies. Not only the variety of dentin bonding systems used (Heymann & Bayne, 1993; Nakabayashi, Nakamura & Yasuda, 1991), but also the characteristics of dentin, have influenced the bonding mechanism and bond strength (Swift, Perdigão & Heymann, 1995; Yoshiyama & others, 1998).

Dentin is a biological composite structure. Dentinal tubules, peritubular dentin and intertubular dentin are three essential structural components of dentin that directly affect adhesive bonding. Dentinal tubules are slightly tapered, with the wider portion located towards the pulp. This tapering is the result of progressive formation of peritubular dentin, the dentin lining of the tubules that causes a continuous decrease in the diameter of the tubule towards enamel; whereas, intertubular dentin is located between the rings of peritubular dentin and constitutes the bulk of circumpulpal dentin (Trowbridge, Kim & Suda, 2002). A number of studies have estimated the size of the tubules, the thickness of the peritubular region and the amount of intertubular dentin (Garberoglio & Brännström, 1976; Fosse, Sæle & Eide, 1992; Mjör & Nordahl, 1996; Schilke & others, 2000). These studies have also shown that these basic structures, altered with different depths of dentin, have varied from location to location.

In order to replace destroyed tooth structure, specific cavity designs and preparations are required based on factors, such as features of the lesion, location of the tooth or types of restorative material chosen. Cagidiaco and others (1997) evaluated the morphology of dentin in cavity walls in terms of tubule orientation, density and surface area. Their observations revealed the variability in dentin morphology at the different areas within any one preparation. These structural differences of the dentin surface may influence the bond mechanism and bond strength of resin to dentin.

Flat dentin surfaces were employed in this study as a means to only focus on variations of the structural components of dentin and eliminate the effects of the cavity configuration factor created by the cavity walls. The micro-shear bond test method allows for the testing of small areas, which permit the precise regional mapping of the dentin surface (McDonough & others, 2002). Furthermore, this test method uses tooth slices as substrates and offers the various depth profiles of dentin surfaces to be prepared in the same tooth, thereby, promoting the conservation of extracted teeth (McDonough & others, 2002; Shimada, Yamaguchi & Tagami, 2002).

This study investigated the influences of dentin location, depth of dentin and tubule orientation on the bond strengths between resin and dentin using two different types of adhesive system. In addition, the interface between the adhesive resins and the corresponding dentin surfaces was observed using a scanning electron microscope.

METHODS AND MATERIALS

The substrate was human, intact upper premolars extracted for orthodontic reasons. The teeth were stored at 4°C in normal saline until used.

Bond Strength Measurement

Table 1 lists the materials, manufacturers, components and batch numbers. The teeth were randomly allocated to two groups. One group was employed as the specimens bonded with the dentinal tubules, running perpendicular to the bonded surface. The other group was employed as the specimens bonded with the tubules running parallel to the surface. Prior to preparation, two locations of dentin were specified for each group. Occlusal dentin was the area located under the occlusal fissure and cervical dentin was located just above the cementum-enamel junction. Therefore, the occlusal and buccal aspects of the tooth were used (Figure 1).

Preparation of Specimens with the Bonding Surface Perpendicular to the Dentinal Tubules

A slow-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) removed the occlusal and buccal enamel under water cooling. From the exposed dentin surfaces, the tooth was further sectioned deep towards the pulp with the remaining dentin thickness approximately

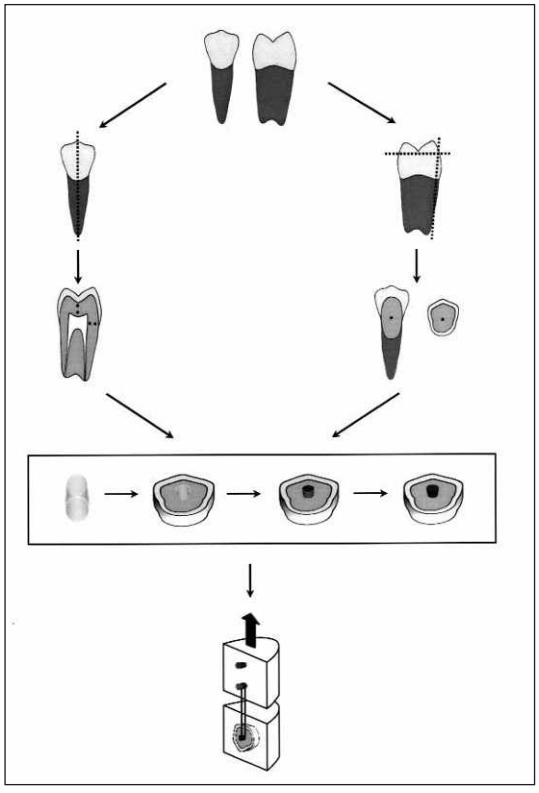

Figure 1. *Schematic diagram of specimen preparation method used for micro-shear bond test.*

0.7 mm. Surfaces obtained from previous preparations were classified as "superficial" and "deep" dentin, respectively. All flat dentin surfaces were polished with 600-grit silicon carbide paper under running water to create a uniform surface and smear layer. The surfaces were treated with one of two adhesive systems according to the manufacturers' directions (Table 2). The resin composite was then placed into a small plastic tube (Tygon, Norton Performance Plastics Corporation, Akron, OH, USA) that was previously attached to each dentin surface at the specified area and photo-irradiated. Because the tube was clear, the resin could be thoroughly cured through the aperture. In this manner, a resin cylinder (approximately 0.5 mm in height and 0.75 mm in diameter) was bonded to the dentin surface (Figure 1). The bonded specimens were stored in water at 37°C for 24 hours until tested.

Preparation of Specimens with the Bonding Surface Parallel to the Dentinal Tubules

The teeth were cut vertically through the middle of the buccal and lingual cusps, separating them into two halves. Each half provided the flat bonded surface that lay parallel to the dentinal tubules. The two levels of dentin depth and preparation were also the same as the perpendicular specimens.

Both the bonded perpendicular and bonded parallel specimens were subjected to micro-shear bond testing. Prior to the test, all plastic tubes were removed and the resin composite cylinders checked at 20x magnification under an optical microscope. Resin cylinders that presented apparent interfacial defects were excluded from the study. The bonded specimens with proper resin cylinder was adhered to the testing device (Bencor Multi-T, Danville Engineering, San Ramon, CA, USA) using a cyanoacrylate adhesive (Zapit, Dental Ventures of America, Corona, CA, USA) which, in succession, was attached to a universal testing machine (EZTest, Shimadzu Corporation, Kyoto, Japan). For the test, a thin wire (0.20-mm diameter) was looped around the resin cylinder and placed close to the resin-dentin interface. With this orientation, the interface, wire loop and center of the loaded cell were aligned as straight as possible to assure the direction of shear test force. The specimens were stressed in shear at a crosshead speed of 1 mm/minute (Figure 1). The shear force at failure was recorded and converted to a shear stress in MPa unit.

Failure Mode

To determine the mode of failure, all fracture surfaces were observed under a confocal laser scanning microscope (1LM21H/W, Lasertec Corporation, Yokohama, Japan). The fractured surfaces were allocated to one of four failure types; adhesive failure at resin-dentin interface (type 1), partial adhesive failure at resin-dentin interface and partial cohesive failure in dentin (type 2), partial adhesive failure at resin-dentin interface and partial cohesive failure in resin layer (type 3) or partial adhesive failure at resin-dentin interface and partial cohesive failure either in the dentin or resin layer (type 4).

Table 1: *Materials, Manufacturers, Batch Numbers and System Compositions*

Material	Manufacturer	Batch #	Material Composition
OptiBond Solo Plus	Kerr, Orange, CA, USA	Etchant: 109433	37.5% phosphoric acid, silica thickener
		Bonding agent: 109364	bis-GMA, GDM, HEMA, GPDM, ethanol
Clearfil SE Bond	Kuraray Medical, Osaka, Japan	Primer: 00219A	MDP, HEMA, hydrophilic overprinted dimethacrylate, photoinitiator, water
		Bonding agent: 00236A	MDP, bis-GMA, HEMA, hydrophobic dimethacrylate, photoinitiator, microfiller
Clearfil AP-X	Kuraray Medical, Osaka, Japan	00772B	Hybrid resin composite containing: bis-GMA, TEGDMA, photoinitiator, microfiller

bis-GMA = bisphenol-glycidyl methacrylate, GDM = glycerol dimethacrylate, GPDM = glycerol phosphate dimethacrylate, HEMA = 2-hydroxyethyl methacrylate, MDP = 10-methacryloyloxydecyl dihydrogen phosphate, TEGDMA = Triethyleneglycol dimethacrylate

Table 2: *Bonding Procedures*

Material	Etching	Priming	Bonding
OptiBond Solo Plus	etch 15 seconds; rinse 15 seconds; gently air dry 5 seconds		apply for 15 seconds with light brushing motion; gently air thin 3 seconds; light cure 20 seconds
Clearfil SE Bond		apply 20 seconds; air dry	apply with brush; air thin; light cure 10 seconds

Scanning Electron Microscopic Evaluation

After the failure mode was evaluated, the specimens were subjected to scanning electron microscopy for verification of the tubule orientation at the bonded surface. The specimens were fixed in 10% neutral buffered formalin for 24 hours and washed in running water for at least 15 minutes. The specimens were air dried and gold sputter-coated. Observation under a scanning

electron microscope was performed to ensure that the tubule orientation was either perpendicular to or parallel to the bonded interface, otherwise they were discarded. The bond strength values obtained from the omitted specimens were not added to the statistical analysis.

Table 3: *ANOVA for Comparison the Effects Among Four Factors*

Source	Sum of Squares	df	Mean Square	F-value	Sig
Model	14656.164	15	977.078	11.488	0.000
Intercept	579467.629	1	579467.629	6813.015	0.000
Location (A)	20.492	1	20.492	0.241	0.624
Depth (B)	9331.363	1	9331.363	109.712	0.000
Orientation (C)	457.976	1	457.976	5.385	0.021
Material (D)	1557.282	1	1557.282	18.310	0.000
A * B	0.452	1	0.452	0.005	0.942
A * C	2.246	1	2.246	0.026	0.871
A * D	8.437	1	8.437	0.099	0.753
B * C	483.133	1	483.133	5.680	0.018
B * D	362.435	1	362.435	4.261	0.040
C * D	1626.276	1	1626.276	19.121	0.000
A * B * C	48.249	1	48.249	0.567	0.452
A * B * D	0.199	1	0.199	0.002	0.961
A * C * D	15.174	1	15.174	0.178	0.673
B * C * D	728.626	1	728.626	8.567	0.004
A * B * C * D	13.824	1	13.824	0.163	0.687
Error	19051.881	224	85.053		
Total	613175.674	240			

Specimen Preparation for the Observation of the Resin-dentin Interface

The teeth were prepared in the same manner as the specimens for the bond strength measurement; however, without placement of the plastic tube, a thin layer of resin composite was applied directly to the treated surface and cured for 40 seconds. After storing in water at 37°C for 24 hours, the bonded specimens were sectioned perpendicular to the resin-dentin interface. The specimens were embedded in an epoxy resin (EPON 815, NISSHIN EM, Tokyo, Japan) and the sectioned surfaces ground with a series of increasingly finer silicon carbide papers and polished with diamond pastes down to a 0.25 µm particle size. Each specimen was subjected to argon-ion beam etching, gold sputter-coated and

Table 4: *Comparison of Bond Strengths ± SD (MPa; n=15)*

Locations		Occlusal Dentin		Cervical Dentin	
Materials		Clearfil SE Bond	OptiBond Solo Plus	Clearfil SE Bond	OptiBond Solo Plus
Superficial dentin	perpendicular*	60.72±13.64^{a,c}	56.82±5.79^{b,c}	59.98±11.65^{A,C}	55.16±12.25^{B,C}
	parallel**	52.72±14.35^{a,d}	52.21±7.83^{b,d}	53.34± 3.41^{A,D}	52.01± 3.69^{B,D}
Deep dentin	perpendicular	50.12± 8.52	35.18±6.62	51.84± 8.47	34.30±14.86
	parallel	43.58± 6.02^{e}	44.05±9.31^{e}	41.15± 2.42^{E}	42.96± 4.99^{E}

**Specimens with the bonding surface perpendicular to the dentinal tubules*

***Specimens with the bonding surface parallel to the dentinal tubules*

Mean values with the same lower case superscript letters are not statistically different (p>0.05) when the bond strengths obtained for occlusal dentin

Mean values with the same upper case superscript letters are not statistically different (p>0.05) when the bond strengths obtained for cervical dentin

Table 5: *Failure Mode Results (n=15)*

Locations		Occlusal Dentin								Cervical Dentin							
Materials		Clearfil SE Bond				OptiBond Solo Plus				Clearfil SE Bond				OptiBond Solo Plus			
Failure Types		*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
Superficial dentin	perpendicular*	-	4	2	9	-	1	3	11	-	1	3	11	-	3	1	11
	parallel**	-	3	3	9	-	3	1	11	-	4	3	8	-	2	4	9
Deep dentin	perpendicular	2	3	2	8	1	3	3	8	-	1	4	10	1	1	5	8
	parallel	-	2	4	9	-	4	4	7	-	2	4	9	-	4	2	9

**Specimens with the bonding surface perpendicular to the dentinal tubules*

***Specimens with the bonding surface parallel to the dentinal tubules*

Failure type 1: adhesive failure at resin-dentin interface

Failure type 2: adhesive failure at resin-dentin interface and partial cohesive failure in dentin

Failure type 3: adhesive failure at resin-dentin interface and partial cohesive failure in resin layer

Failure type 4: adhesive failure at resin-dentin interface and partial cohesive failure either in dentin or in resin layer

No statistically significant differences (p>0.05) when the failure modes were compared within each factor

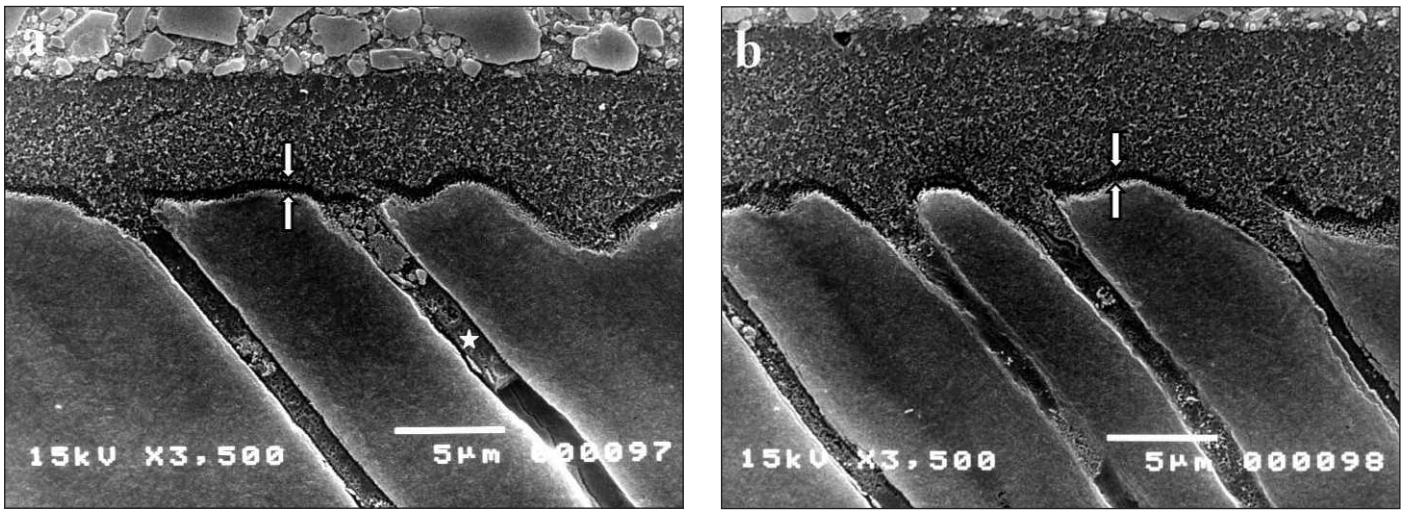

Figure 2. *SEM photographs of superficial dentin (a) and deep dentin (b) bonded perpendicular to the tubules using Clearfil SE Bond. The thickness of hybrid layer is less than 1 µm (arrows), being independent of the dentin depth. The thin resin tag (star) can be observed (original magnification=3500; bar=5 µm).*

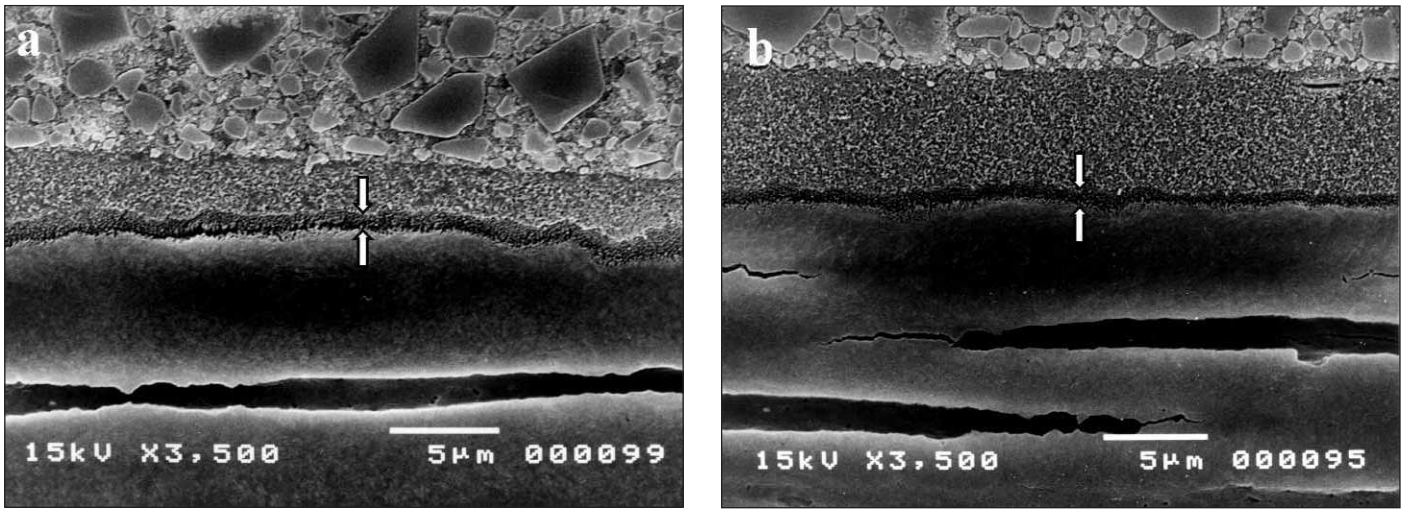

Figure 3. *SEM photographs of superficial dentin (a) and deep dentin (b) bonded parallel to the tubules using Clearfil SE Bond. The thickness of hybrid layer is less than 1 µm (arrows), being independent of the dentin depth. No resin tag can be observed (original magnification=3500; bar=5 µm).*

observed using a scanning electron microscope (JSM-5310LV, JEOL, Tokyo, Japan).

Statistical Analysis

After verification of tubule orientation under SEM, 15 precise bond strength values were obtained for each tested group, resulting in an overall total of 240 values for 16 groups. The mean and standard deviation of the shear bond strengths were calculated for each group. The multi-way factorial analysis of variance (ANOVA) was performed to identify statistical interactions between the dentin location, dentin depth, tubule orientation and bonding systems. The bond strengths between both groups of each factor within each comparison were analyzed using independent *t*-test. An analysis of failure mode was performed using the same comparison as the bond strength values, but the Mann-Whitney *U*-test for non-parametric data was used.

RESULTS

Bond Strength Measurement

Multi-way factorial ANOVA revealed significant differences in shear bond strength based on the depth of dentin, tubule orientation, bonding systems and their interactions. However, for dentin location, statistically significant differences were not found separately nor were they concomitantly determined with other factors (Table 3). Therefore, the mean shear bond strengths and standard deviations for each dentin location were disjointedly given (Table 4). Deep dentin produced lower bond strengths than superficial dentin ($p<0.05$) irre-

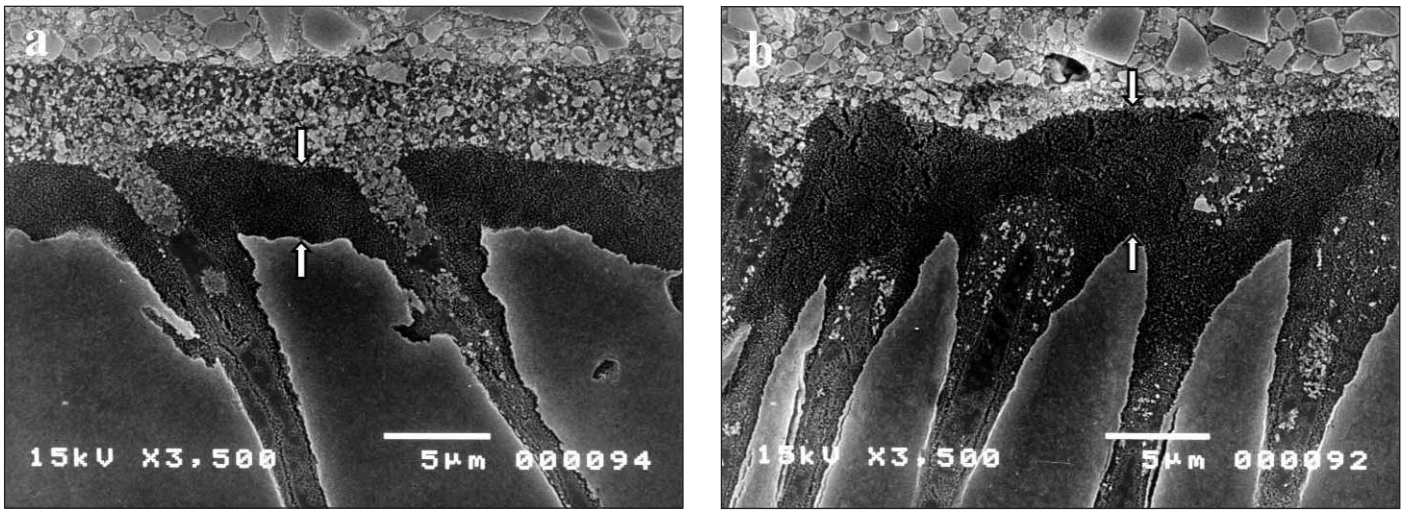

Figure 4. *SEM photographs of specimens bonded perpendicular to the tubules using OptiBond Solo Plus. (a) superficial dentin; the hybrid layer is about 3 µm thick (arrows); (b) deep dentin; the thickness of the hybrid layer is about twice that of superficial dentin (original magnification=3500; bar=5 µm).*

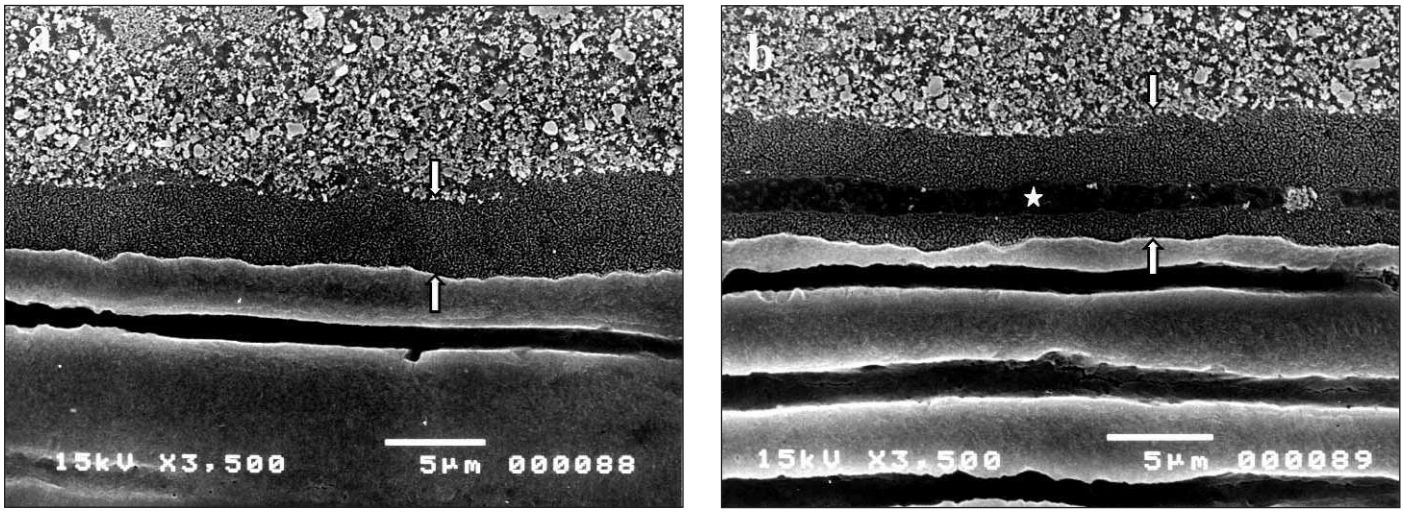

Figure 5. *SEM photographs of specimens bond parallel to the tubules using OptiBond Solo Plus. (a) superficial dentin; the hybrid layer is about 3 µm thick (arrows) and no resin tag can be observed; (b) deep dentin; hybrid layer is about 6 µm thick and resin tag (star) is observed within the hybrid layer (original magnification = 3500; bar=5 µm).*

spective of any factors. For deep dentin specimens bonded with Clearfil SE Bond, the bond strengths obtained for those specimens bonded perpendicular to the tubules were higher than those bonded parallel to the tubules ($p<0.05$). For deep dentin specimens bonded with OptiBond Solo Plus, bond strengths obtained for specimens bonded perpendicular to the tubules were lower than those that bonded parallel to the tubules ($p<0.05$). However, there were no statistically significant differences ($p>0.05$) for either Clearfil SE Bond or OptiBond Solo Plus when the bond strengths of superficial dentin were compared among the different orientations of tubule. A comparison of bond strengths between the two bonding systems for each depth of dentin and tubule orientation showed that OptiBond Solo Plus produced significantly lower values than Clearfil SE Bond ($p<0.05$) for deep dentin specimens bonded perpendicular to the tubules.

Failure Mode

Table 5 illustrates the modes of failure for each group. No statistically significant differences in failure modes were indicated for each factor ($p>0.05$). The fracture surfaces were predominantly in mixed type composed of adhesive failure associated with cohesive failure both in the dentin and resin layer. Neither cohesive failure in dentin nor in the resin layer was totally observed in any fracture surfaces.

Observation of the Resin-dentin Interface

For specimens that used Clearfil SE Bond bonded perpendicular to the tubules, hybrid layers and resin tags could be observed (Figure 2). The resin also showed that it could penetrate through the dissolved smear plug remnant and form very slim tags (Figure 2a). For specimens bonded parallel to the tubules, no resin tags were observed (Figure 3). The thickness of the hybrid layer was less than 1 μm and was independent of the dentin depth and orientation of the tubule.

For OptiBond Solo Plus, the hybrid layers and resin tags could be clearly observed. The thickness of the hybrid layer for superficial dentin bonded either perpendicular to or parallel to the tubules was similar, at about 3 μm. (Figures 4a and 5a). The hybrid layer thickness for deep dentin was about twice the thickness of the superficial dentin (Figures 4b and 5b). For deep dentin specimens bonded parallel to the tubules, the resin tag could be discerned along with the hybrid layer. The hybridized dentin was created not only under the bonded interface but also beneath the resin tag (Figure 5b).

DISCUSSION

Both dentin bonding systems employed in this study exhibited significantly lower bond strengths when bonded to a deeper dentin, which agreed with previous findings (Mitchem & Gronas, 1986; Tao & Pashley, 1988; Burrow & others, 1994). As noted in the Introduction, tapering of the dentinal tubule towards the enamel causes an increase in the area of intertubular dentin when compared with deep dentin. It has even been reported that the dentinal tubule volume of deep dentin was seven times higher than superficial dentin (Heymann & Bayne, 1993), thus, enhancing how resin penetrates into and forms tags; the strength of bond was lower. To establish a good bond, permeation of the resin into intertubular dentin appeared to be more important than the resin tags in dentinal tubules. The current observation affirms the significance of mechanical bonding by the creation of an intermixture of adhesive resins with components of dentin referred to as the "hybrid" layer (Nakabayashi & others, 1982, 1991). This concept of a bonding mechanism was accepted as the principle mechanism for bonding adhesive resin and dentin (Pashley & others, 1993; Walshaw & McComb, 1996; Eick & others, 1997).

When dentin was prepared perpendicular to an array of dentinal tubules, peritubular dentin was observed only at the area that surrounded the tubular orifices. Compared with what was parallel, prepared peritubular dentin was covered along the streaks of cut tubule. Therefore, dentin with tubules that run parallel has a greater amount of peritubular dentin than dentin with tubules that run perpendicular, resulting in a lesser area of intertubular dentin to form the hybrid layer (Olsson, Öilo & Adamczak, 1993). Previous studies also reported the increase in peritubular dentin may prevent the development of an adequate micromechanical retention of resin (Duke & Lindemuth, 1990). This might explain why lower bond strength presented in specimens bonded parallel to the tubules. Superficial dentin, even though there was no statistical difference, also exhibited the same tendency as previous described. However, in deep dentin, it was legitimate only for the specimens bonded with Clearfil SE Bond. The contributory factor related to the different dentin bonding systems might have caused this disagreement. For OptiBond Solo Plus, phosphoric acid is used to demineralize the dentin in order to remove the smear layer and smear plugs. This rather strong acid also greatly decalcifies intertubular dentin and peritubular dentin, resulting in an enlargement of dentinal tubule orifices (Swift & others, 1995). Residual water that was left behind after the post-conditioning rinsing step might remain in the abundant, enlarged lumens of the tubules and water perfusion could occur, creating an excess of surface moisture. Even in this study, dentin slabs were prepared prior to the bonding procedure so that the influence of pulpal pressure was eliminated, the presence of excessive water on dentin surface might still be an additional factor that affects bond strength. Pereira and others (1999) reported the lower bond strength of the phosphoric acid etching adhesive system to dentin over the pulpal horn region, classified as deep dentin when the remaining dentin thickness was considered, under non-hydrostatic pressure conditions. These authors also indicated that, by completely removing the smear layer and plugs during etching and rinsing, water perfusion could occur and had affected the bond strength even without pulpal pressure. When OptiBond Solo Plus was used, greater water content was found in deep dentin bonded perpendicular to the tubules, therefore, causing a diminished bond strength.

On the other hand, dentin with tubules that run parallel presents no openings of the tubules that directly communicate to the bond surface. Excessive water might not conceal in the bonded parallel specimens, resulting in no influence of residual water to dentin bond strength. In addition, deep demineralization created by phosphoric acid plus the close distance between the adjacent dentinal tubules provided a great opportunity for the tubules that run beneath the surface to be enfolded in an acid-etched dentin. The resin could more easily penetrate not only directly from the exposed dentin surface but also from the lumen of the dentinal tubule to the surrounding demineralized dentin (Ogata & others, 2001). Because the resin diffused via both routes, penetration of resin, especially into the bottom of the demineralized dentin, was plausibly created and enhanced the higher bond strength.

For Clearfil SE Bond, self-etching primer partially demineralizes the smear layer and underlying dentin surface without unplugging or even severely enlarging the tubule orifices (Eick & others, 1997). Partially dissolved smear plugs still remain within the tubules, lowering the dentin permeability and diminishing the sensitivity to excess water. Moreover, by omitting a post-conditioning rinsing step, the primer is only air-dispersed and complication of the wet bonding technique is avoided (Kugel & Ferrari, 2000). With lower technique sensitivity, it was reported that the self-etching adhesive system creates relatively uniform bond strength to dentin (Pereira & others, 1999) and the decrease in bond strength when specimens were bonded parallel to the tubules might be directly due to the lesser amount of intertubular dentin that forms the hybrid layer.

Although bond strength values obtained from this study were affected by the depth of dentin, tubule orientation and bonding systems, the dentin location did not exert any influences on bond strength. Mjör and Nordahl (1996), focusing on the density and branching of dentinal tubules, showed that both observations did not differ in the area under the occlusal fissure and cervical area that corresponded to the cementum-enamel junction. The similarities in bond strengths presented in this study might be attributed to the similarities in the characteristics of dentin substrate of both locations. An alternative explanation is that the teeth used in this study were extracted for orthodontic reasons. No previous restorations or surface alterations, such as dental caries or cervical abrasion, were detected. It might be assumed that all employed dentin was in approximately the same age and classified as normal dentin.

SEM photographs demonstrated that characteristics of the hybrid layer varied from material to material and showed some variation in dentin depth and tubule orientation. For specimens bonded with Clearfil SE Bond, a distinctly thin hybrid layer was observed irrespective of the dentin depth or tubule orientation (Figures 2 and 3). This is due to the relatively mild dentin demineralization of the self-etching primer used. In contrast, phosphoric acid used in OptiBond Solo Plus created a much thicker layer of demineralized dentin collagen (Figures 4 and 5). A double thickness of the hybrid layer in deep dentin was also detected, as it may be expected since deep dentin is likely to be lower in degree of calcification. The integration of resin tag into the hybrid layer was observed in the group of deep dentin specimens bonded parallel to the tubules that used OptiBond Solo Plus (Figure 5b). The aggressive acid-etching procedure could remove all peritubular dentinal matrices, exposing the circumferentially oriented collagen fibrils and permitting the resin to radially diffuse into surrounded demineralized dentin (Ogata & others, 2001). However, it is not known whether peritubular dentin cannot be fully removed. In such a situation, the resin might not be able to penetrate through the highly mineralized peritubular dentin. An unconsummated hybrid layer might occur and possibly contribute to an inadequate adhesion. It is interesting that, based only on SEM observation, the authors might not obtain enough information about the bonding performance of adhesive material. The characterizations of the hybrid layer observed by SEM, such as thickness, were variable and did not present any relation to the values of bond strength. Hence, in order to determine the bonding performance of any adhesive materials, other evaluations should be taken into account, such as bond strength value or bonding durability.

In this study, both adhesive systems showed similar modes of failure, which were predominantly partial adhesive failure, along with cohesive failure both in resin layer and dentin. Even with a significant number of fractured surfaces showing failure in dentin, no correlation to the values of bond strength was found. It has been clearly shown that the dentin pull-out was, in fact, partly due to the mechanics of the shear test and stress distribution and did not necessarily indicate excellent adhesive strength (Versluis, Tantbirojn & Douglas, 1997). DeHoff, Anusavice and Wang (1995) stated that the magnitude of stress concentration effect and stress distribution of the shear test depended on the type of loading. Because the stress applied in the wire-loop loading method was distributed over 180° along the resin-dentin interface, it was presented as reducing the stress concentration magnitude at the loading site (DeHoff & others, 1995). Hence, this method of load application was selected for use in the current study with the intention of improving the loading condition. However, further improvement, including specimen preparation, is still needed. To obtain the precise regional mapping of tooth structure, resin must be bonded to the limited area restricted by the lumen of plastic tube. It was quite difficult to condense the resin composite into a small tube, leading to some pre-testing failures such as interfacial gap formation and bubble inclusion. This micro-bond test method is now continually being improved for the better manipulation.

Within the limitations of this *in-vitro* study, the results were obtained under conditions rather far from those in clinical situations. Other factors can also affect dentin bonding, such as cavity configuration and the alteration of dentin morphology caused by aging or the carious process (Tagami & others, 1993; Nakajima & others, 1995; Yoshikawa & others, 1999). However, it was partly demonstrated that the dentin bonding materials did not adequately adhere to all parts of the tooth. Dentin depth and orientation of the dentinal tubule were two factors that influenced the shear bond strengths and differences in shear bond strengths were also material dependent.

CONCLUSIONS

The shear bond strengths of resin were influenced not only by the adhesive material used but also by the differences in characteristics of the dentin surface. In this study, the level of dentin depth and orientation of the dentinal tubule were two characteristics that contributed to variations in bond strengths.

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Clinical Technique/Case Report

Combined Amalgam and Composite Restorations

AA Abu-Hanna • IA Mjör

SUMMARY

All indirect restorative techniques involving cast metals, ceramics or resin-based materials are expensive compared to directly placed restorations. A restorative technique is presented that combines the esthetic properties of directly bonded resin-based composite material and the wide range of indications for dental amalgam in stress-bearing areas.

INTRODUCTION

For most patients, the esthetic outcome of restorative treatment is important. Therefore, teeth that are visible during normal function should be esthetically restored and/or recontoured whenever needed to maintain or improve their appearance. Today, many tooth-colored materials are available that provide optimal esthetics in restorative dentistry. However, in the treatment of extensively broken down teeth, esthetically pleasing results often require indirectly prepared restorations involving cast metal, ceramic and/or resin materials that are relatively costly and, therefore, out of reach for much of the population, including many dental school patients. For these patients, low cost alternative esthetic treatment must be sought, especially if extraction of the tooth is the only alternative treatment.

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METHODS AND MATERIALS

Amalgam provides the least costly directly placed restoration. Their placement is not technique sensitive and they are durable. Amalgam has a wide range of indications and amalgam restorations serve well under a variety of conditions. However, they are esthetically displeasing and require a sound basis in tooth structure to prevent fracture of the weak parts of the tooth over time.

A variety of resin-based, tooth-colored direct restorative materials is available and will be referred to as composites. They represent the only realistic alternative to amalgam for large, directly placed posterior restorations. However, for a long time after their introduction, they were not considered suitable for posterior restorations (Mjör & Wilson, 1998; Wilson & Mjör, 2000) mainly because of wear/degradation and polymerization shrinkage of the materials. Many teaching programs still hesitate to recommend large composite restorations in molars, despite improved physical properties of the materials.

Apart from color, some of the characteristics of present day composites have clinical properties similar to amalgam (Mjör, Moorhead & Dahl, 2000). However,

contraction stresses still remain a major problem, especially for severely compromised teeth with weak, undermined cusps. If large areas of undermined enamel are present, they tend to fracture *in situ* during or soon after insertion of the restoration, even if they are incrementally inserted, because of the inherent polymerization shrinkage of the materials. Resin-based composite materials are also technique sensitive. Furthermore, they bond better to enamel than to dentin and, therefore, are not suitable when the cavosurface margin is in dentin, especially if moisture control is difficult as in situations where the gingival floor of an interproximal posterior restoration is located in dentin.

The so-called "amalgabond technique" combines the bonding properties of resin-based materials and the durability of amalgam restorations, but they are as unsightly as amalgam restorations.

AN ALTERNATIVE RESTORATIVE TECHNIQUE

Attempts have been made to combine the main advantages of amalgams and composites by combining the two materials for the restoration of severely broken down teeth, namely, the bonding/strengthening and esthetic properties of resin-based composite materials and the durability, wear resistance and strength of amalgam. This report will illustrate two cases where "combi-restorations" use composite and amalgam to restore teeth that normally would require indirect restorations that often require root canal treatment to obtain adequate retention.

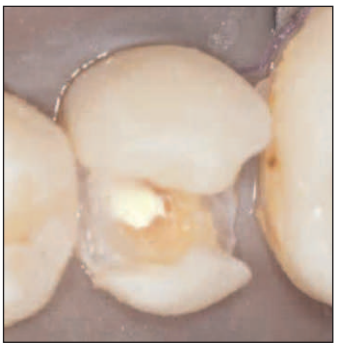
CASE REPORTS

Case 1

A severely broken down second mandibular premolar in a patient with many active caries lesions was scheduled for an MOD amalgam restoration. After cavity preparation and excavation of the soft carious tissue (Figure 1), only buccal and lingual cusps that comprise mainly enamel remained. The preparation also extended buccally on the mesial aspect of the tooth. A build-up of the tooth followed by crown preparation was not considered feasible because virtually all of the remaining buccal and lingual cusps would be lost during preparation, leaving no abutment for a crown. For financial reasons, root canal treatment followed by a post and core for retention of a crown was not acceptable to the patient.

As an alternative treatment, the mesiobuccal part of the tooth was restored with a hybrid composite (Feltic Z250, 3M ESPE, St Paul, MN, USA) after conventional acid etching and bonding technique (Single Bond, 3M ESPE) (Figure 2). The resin composite was added free-handed in one increment and without the use of a matrix. A hybrid composite resin material was used due to its universal acceptance as a posterior resin composite material. Prior to the etching and bonding procedure, a metal matrix was placed on the mesial to protect the adjacent tooth.

Figure 1.



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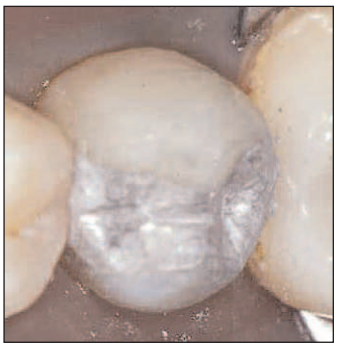

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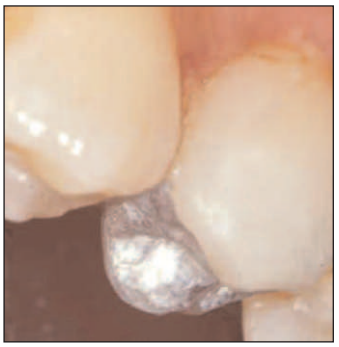


Figure 4.

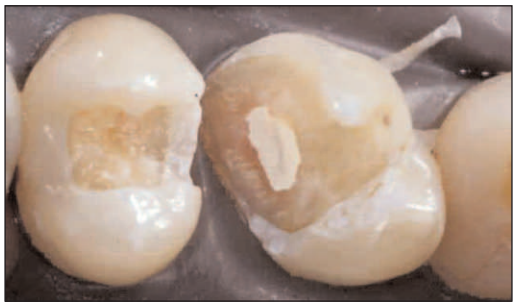
The aim of this procedure was to alleviate major esthetic concern. The remaining part of the MOD preparation was restored with amalgam (Dispersalloy, Dentsply/Caulk, Milford, DE, USA) (Figure 3). The appearance of the restored tooth (Figure 4) satisfied the patient's esthetic demands.

Case 2

Approximately half of the buccal cusp of an upper first maxillary premolar had been destroyed by caries (Figure 5), and if restored by amalgam, would provide an unsightly restoration. An amalgam restoration was also required for the adjacent second premolar. Since the expenses of a crown for the first premolar was not acceptable to the patient, the buccal and gingival part of the preparation was restored with a composite material in two increments using the same materials and techniques as in Case 1, leaving a normal-sized retentive Class II cavity (Figure 6). The remaining part of the cavity was then restored with amalgam (Figure 7). The second premolar was restored with amalgam and an esthetically satisfactory result was obtained (Figure 8).

An alternative technique would be to first place the amalgam restoration, then prepare the amalgam on a second appointment to veneer the mesiobuccal part

with the resin composite. This alternative is only recommended in the case of an existing old amalgam due to the additional appointment needed to complete this procedure and the added expense. Additionally, another disadvantage to this technique is the lack of an oxygen-inhibited layer that may provide a stronger link between the composite and the amalgam (Cobb, Denehy & Vargas, 1999).



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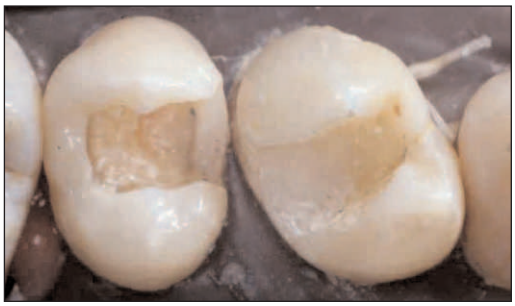

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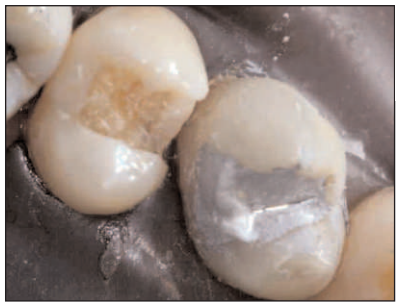

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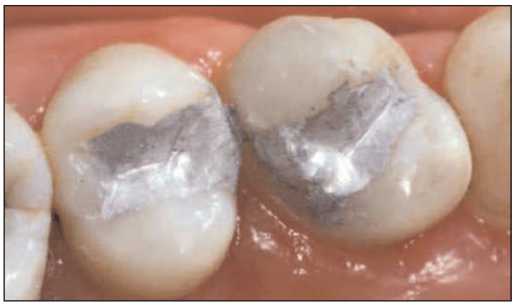

Figure 8.

The authors have limited experience with the type of combi-restorations described, and long-term data are not yet available. A six-month recall examination indicates no problems. Furthermore, the patients are instructed to report back if any part of the restoration or tooth fractures off and they will be recalled for a routine check-up. So far, no problems have been encountered and the patients are pleased with the results.

The authors would appreciate comments from any colleagues who utilize this technique.

CONCLUSIONS

Combi-restorations aim to use the positive properties of the two materials involved, providing an esthetically acceptable, strong, wear-resistant and durable restoration as a compromise to an indirect restoration where financial limitations do not permit an ideal type of treatment. The charge for the restoration is suggested to be that of a comparable composite restoration.

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A Tofflemire® Time Saving Tip

JS Blalock

As operative dentists, we are constantly challenged with ways to creatively restore a carious dentition. This has held true for dentistry since its inception. Today, with the advent of fluoride, it is common knowledge that the caries rate has been reduced. However, it is still not abolished. We still have the responsibility to restore teeth in order to maintain form and function.

As dentists, we know that a common site for caries to occur is the interproximal, often adjacent surfaces are involved. The traditional way to restore these carious lesions is a Class II amalgam, and in more recent years, a Class II posterior composite. As a private practitioner, I was concerned with doing good work in the least amount time while keeping the patient comfortable. I developed a technique for restoring these adjacent lesions simultaneously, while using one Tofflemire retainer (Teledyne Waterpick). This technique provides a good result, saves time and is more comfortable for the patient.

• First, the teeth to be restored must be adjacent and must be the same type. (The carious teeth must be both molars or premolars.)

• Preparations for both teeth should be completed as usual.

• Two bands (Teledyne Waterpick tofflemire) should be placed side-by-side and one end held static, while the opposite ends are looped away from each other. This should create two loops with the four loose ends of the band now being adjacent.

• These four ends should be placed in the Tofflemire retainer and secured as usual.

• Next, place bands around the teeth to be restored and tighten the retainer (Figure 1).

The next step is critical—the wedge (Figure 2).

• Select a large enough wedge to get some separation of the teeth in order to achieve a good proximal contact and insert.

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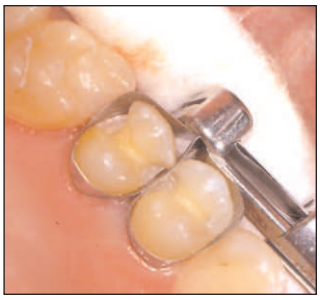
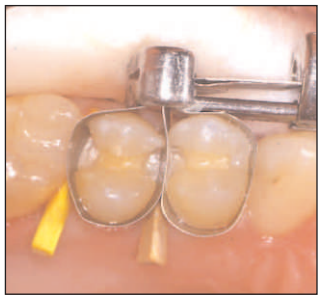


Figure 1.



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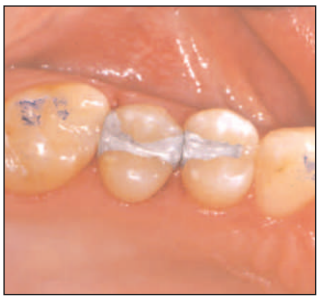

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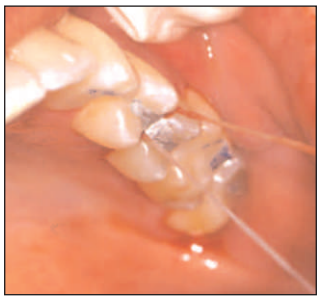

Figure 4.

• Restore the teeth by condensing amalgam (or composite) incrementally into the preparations, swapping back and forth between the two teeth. In other words, do not fill one to completion, then the other, but take turns filling. This ensures that both teeth will have a good convex profile or contour. If you fill one tooth to completion, then do the next, you run the risk of the first tooth being over contoured and the second tooth wrapping around the first (Figure 3).

• Following condensation, proceed as usual and use caution when removing the bands (Figure 4).

This technique has a slight learning curve, but if you are already restoring adjacent teeth with two Tofflemires, then it is basically the same. The exceptions are less work for the dentist and more comfort for the patient.

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FIT CHECKER® for All Ceramic Restorations

RM Pohjola

The increased use of all-ceramic crowns and inlays has identified the need for a fit checking material that is more suitable for these types of restorations. The conventional materials are white and provide very little contrast when used with all-ceramic restorations. This makes finding areas of internal binding and interference difficult to identify. A simple technique is proposed to change the color of the existing material to make it easier to identify areas that need adjustments.

When dispensing (Figure 1) FIT CHECKER® (GC Corporation, Tokyo, Japan) mix a drop of caries detector liquid, disclosing liquid or food coloring to the catalyst (Figure 2). Then mix with the base and use as directed. This addition of color will increase the contrast between the fit-checker material and the ceramic and will make the pressure points more evident (Figures 3 and 4). Mixing the colored liquid with the catalyst first eliminates the chance of staining the ceramic.

(Received 10 March 2003)

Figure 1. *Caries detector added to the mixing pad.*

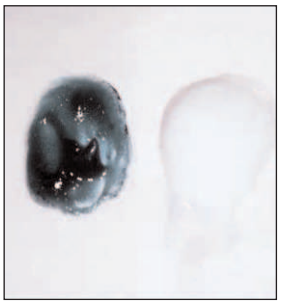

Figure 2. *Caries detector mixed with catalyst.*

Figure 3. *FIT CHECKER without color. Contrast with the ceramic is limited.*

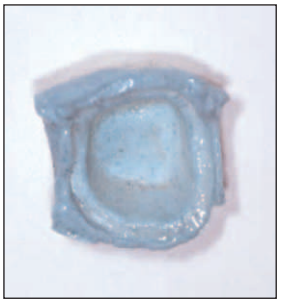

Figure 4. *FIT-CHECKER with color added. Contrast with the ceramic is improved.*

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Direct Composite Bonding in Conjunction with Surgical Tissue Management

JW Robbins

The provision of restorative dentistry in the esthetic zone requires more than an understanding of current restorative materials. With the increased emphasis on facial and dental esthetics, the restorative dentist must also understand and manage the perio-restorative interface.

The concept of biologic width was first described by Cohen (Ingber, Rose & Coslet, 1977), based on the research of Gargiulo, Wentz and Orban (1961). The biologic width, as defined by Cohen, is the distance from the base of the gingival sulcus to the crest of the alveolar bone. These authors reported mean measurements of .97 mm for the epithelial attachment and 1.07 mm for the connective tissue attachment. Adding these two dimensions together resulted in the oft-quoted biologic width of 2.04 mm. Although helpful as a starting place in understanding the perio-restorative interface, restorative dentists have struggled for many years with their inability to predict the response of the attachment apparatus to restoration margins.

In recent years, Kois (1994) proposed that the key measurement is the distance from the gingival crest to the alveolar crest. In order to measure this distance, the gingiva is anesthetized and a periodontal probe is placed in the gingival sulcus. The probe is pushed through the epithelium and connective tissue until the tip engages the alveolar crest. This procedure is termed bone sounding. Kois described three categories of biologic width: Normal Crest, Low Crest and High Crest.

In the normal crest patient, the distance from the gingival crest to the alveolar crest is 3 mm when measured mid-facially on a maxillary anterior tooth. When measured interproximally, the distance from the tip of the papilla to the crest of the bone is a range between 3 mm and 4.5 mm, depending on the degree of gingival scallop. Normal crest occurs approximately 85% of the time and is a stable gingival dimension.

In the low crest patient, the gingival crest to alveolar crest dimension is greater than 3 mm mid-facially and 4.5 mm interproximally. Low crest patients occur less frequently, approximately 13% of the time. However, they present a difficult treatment situation for the restorative dentist. When the attachment apparatus is injured during placement of the retraction cord, the tissue is susceptible to recession and tends to recede back to the 3 mm normal crest position. This can result in unacceptable esthetics due to exposure of the crown margin and/or open gingival embrasure. The keys to treating the low crest patient are to surgically transform to normal crest, if possible, to avoid trauma to the gingival tissues and inform the patient and predict recession.

In the high crest patient, the gingival crest to alveolar crest dimension is less than 3 mm, both mid-facially and interproximally. This situation occurs approximately 2% of the time. The major risk with this group of patients is inadvertent impingement on the biologic width during crown preparation. Ideally, the crown margin should be at least 2.5 mm from the alveolar crest. Therefore, if an intracrevicular crown margin is placed in the high crest patient, a biologic width impingement commonly occurs, resulting in long-term marginal inflammation.

This more current understanding of the biologic width has been very helpful in planning the position of restoration margins that results in long-term tissue stability and decreased risk of chronic gingival inflammation or gingival recession. This article presents a case report that demonstrates the importance of understanding biologic width when planning restorative therapy.

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Case Report

A 15 year-old female was referred from her orthodontist for consultation. Her chief complaint was her small maxillary anterior teeth with resultant spacing. Due to a tooth arch size discrepancy, the orthodontist was unable to close the interdental spaces between the maxillary teeth. In addition, the examination revealed that the interdental spaces were almost filled with gingival tissue and an asymmetrical gingival margin that was too coronal on the maxillary right lateral incisor (tooth #7) (Figure 1).

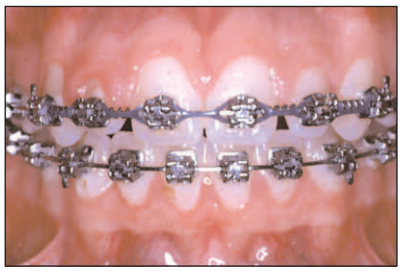


Figure 1. *Pre-operative view of the short clinical crown on the maxillary right lateral incisor.*

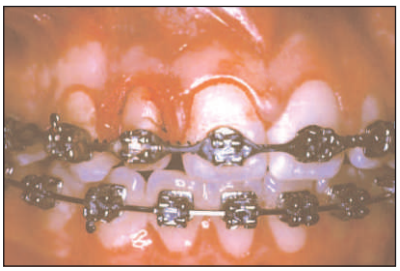
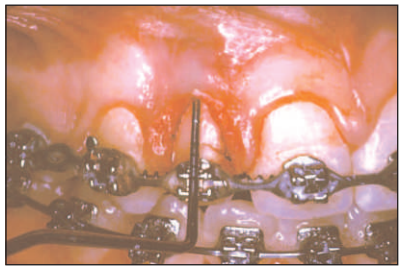


Figure 2. *Post-operative view after the gingivectomy on the right maxillary lateral incisor.*

In order to diagnose the etiology of the coronally situated gingival margin on tooth #7, an explorer tip was used to feel for the cementoenamel junction (CEJ) in the gingival sulcus. The CEJ could not be felt and the tooth was short incisogingivally compared to the contralateral maxillary lateral incisor; therefore, a diagnosis of altered passive eruption was made (Dolt & Robbins, 1997). Since the CEJs were palpable in the sulci of the remaining maxillary anterior teeth, the altered passive eruption was found only on tooth #7. At this time, it was impossible to determine the actual level of the CEJ on tooth #7. Since the ultimate goal was to have the CEJ on tooth #7 level with the CEJ on tooth #10, crown-lengthening surgery was accomplished on tooth #7 prior to removing the orthodontic appliances. This treatment sequence allows the orthodontist to intrude or extrude tooth #10 after crown lengthening surgery, if necessary, to level the CEJs.



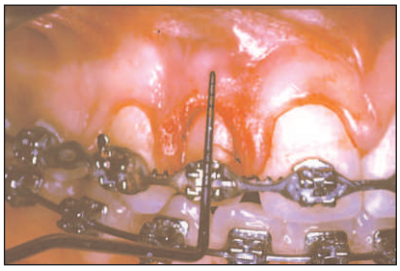


Figure 3 and 4. *Bone sounding after the closed ostectomy procedure demonstrating the required 3-mm distance from gingival crest to alveolar crest.*

At the time of surgery, the patient was anesthetized and the bone sounding procedure was accomplished on tooth #7. On the mid-facial surface, the distance from the gingival crest to the alveolar crest was 3 mm (normal crest). A sulcular incision was made to the alveolar crest on the facial surface of tooth #7. The explorer tip was then placed in the gingival sulcus in an attempt to feel the CEJ. Using the explorer, the CEJ was located approximately 2 mm apical to the gingival crest. It was next determined that in order to even the gingival level of tooth #7 with the gingival level on tooth #10, approximately 1.5 mm of gingival tissue must be removed on tooth #7. There was adequate keratinized tissue on tooth #7 (approximately 5 mm); therefore, a 1.5 mm gingivectomy was accomplished with a single wire electrosurgery tip (Figure 2). Now, the distance from the gingival crest to alveolar crest was only 1.5 mm. In order to recreate the normal crest dimension of 3 mm, approximately 1.5 mm of facial alveolar bone must be removed. This can be accomplished as an open procedure with a full thickness flap and osseous resection with rotary instruments and hand chisels. Alternatively, the ostectomy can be accomplished as a closed procedure without a flap. This technique is technically demanding; however, it results in much faster healing and a decreased risk of scarring. Since ostectomy was only required on one tooth, the closed procedure was chosen. A sharp Wedelstaedt chisel was placed in the sulcus with the bevel out until the alveolar crest was engaged. Approximately 1.5 mm of facial alveolar bone was removed from the mesiofacial line angle to the distofacial line angle and the bone fragments were irrigated out with the aid of an ultrasonic scaler. The desired 3-mm distance from the gingival crest to the alveolar crest was confirmed by bone sounding with the periodontal probe (Figures 3 and 4). Direct pressure was placed over the surgical site for one minute and the procedure was complete. During the surgical procedure, it was determined that the CEJs on teeth #7 and #10 were level; therefore, no further orthodontic movement was required on tooth #7 (Figure 5).

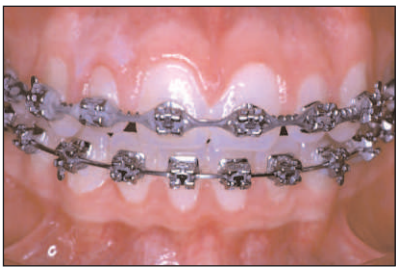
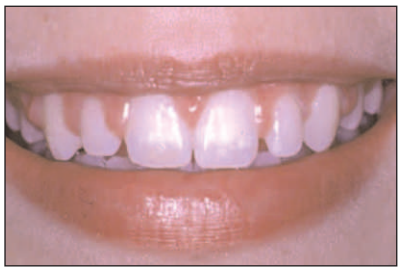


Figure 5. *One-week post-operative view.*

Orthodontic appliances were removed approximately three months later and the patient received a prophylaxis and oral hygiene instructions were reviewed. Much of the gingival inflammation was resolved in two weeks. However, in the absence of inflammation, excess



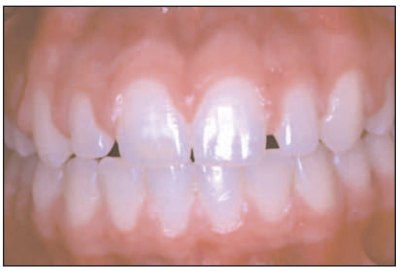


Figure 6 and 7. *Four month post-surgical views after removal of orthodontic appliances.*

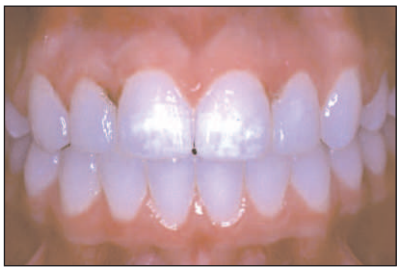
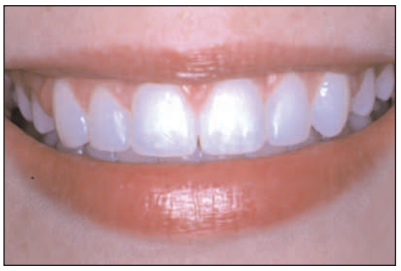


Figure 8. *Immediate post-operative composite bonding view. Note the areas of interproximal gingival recontouring on the right and left lateral incisors.*

interdental tissue remained in the spaces between all of the anterior teeth (Figures 6 and 7).

After a discussion of treatment options for diastema closure, the patient and her parents chose direct composite bonding. The excess interdental tissue almost completely filled the interdental spaces, making diastema closure impossible. However, the tissue could not be removed pre-restoratively and allowed to heal due to its propensity to quickly refill the interdental spaces. Therefore, interdental tissue recontouring was accomplished in conjunction with the direct composite bonding procedure. Soft tissue anesthesia was obtained and the interdental papillae were recontoured with a single wire electrosurgery tip. The tissue was recontoured to create an esthetically pleasing papilla tip, which was approximately 4 mm from the alveolar crest, as confirmed by interproximal bone sounding. Isolation was accomplished with retraction cord that had been soaked in aluminum chloride. Using traditional methods, direct composite bonding procedures were used interproximally and incisally on the maxillary anterior teeth with the exception of the left canine tooth (teeth #6-10) (Figures 8 to 10).



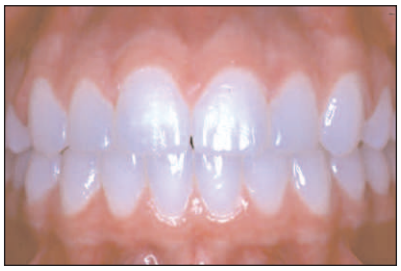


Figure 9 and 10. *One-week post-operative composite bonding views.*

SUMMARY

This article discussed several issues associated with the intimate relationship between attachment apparatus and the restorative interface. First, it is essential that the restorative dentist have a clear understanding of crest position and its impact on the restorative outcome. Then, the restorative dentist must understand the importance of sequencing and timing when orthodontic therapy, tissue recontouring and restorative dentistry must be accomplished on the same patient.

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Technique on Restoring Sub-gingival Cervical Lesion

DCN Chan • J Adkins

Clinical Relevance

This combination technique provides an atraumatic approach for the management of a difficult, deep, proximal-cervical Class V lesion with a resin-modified glass ionomer restorative material.

INTRODUCTION

The incidence of root caries has been found to increase as the population ages and as edentulism becomes less prevalent due to improved dental awareness and care (Ramamurthy & others, 1998). The exposure of roots has also increased in the elderly due to gingival recession. This might be a predisposition to abrasion lesions.

Restoring root caries and abrasion lesions has always been a challenge. Matis and Cochran (2002) described a technique that works well with abrasion lesions. The technique entails placing a semi-rigid cervical matrix slightly past the cervical border of a lesion that extends below (apical to) the gingival crest, then inserting the glass ionomer cement through an opening cut in the matrix above the soft tissue level. Other authors proposed similar techniques utilizing a matrix with an access hole for proximal cervical root caries (Gilboa & Cardash, 2003; Setien, Armstrong & Vargas, 2003). One innovative approach includes the use of clear plastic drinking straws for upper and lower bicuspids with abrasion lesions (Proto, 1998).

In situations where deep root caries lesions occur at the gingival cavosurface margin of a Class V cavity, the methods previously proposed may not be adequate. There are several options for restoring this type of deep lesion. Matis and Cochran (2002) mentioned crown lengthening, a retraction clamp and the surgical mini-flap technique. Each method has its advantages and disadvantages.

This paper describes a combination technique to retract the tissue with a 212-retraction clamp and to release the tissue with a blunt instrument such as the cord-packing instrument. Adaptation and stabilization of the matrix band is also illustrated, where the cervical cavosurface margin extends sub-gingivally and the proximal margins extend beyond the mesial and distal line angles. A resin-modified glass ionomer material was prescribed for the situation.

TECHNIQUE

A 69 year-old Caucasian female presented with tooth #25 showing Class V cervical caries extending sub-gingivally. Figures 1 and 2 show the pre-operative clinical picture and radiograph. The tooth was asymptomatic.

1. After anesthesia was obtained, the mandibular anteriors were isolated with cord-retained rubber dam placement (Wedjets, Coltene/Whaledent Inc, Mahwah, NJ, USA).

2. The facial gingival tissue was carefully released with a blunt instrument to minimize tearing of tissue. The challenge was to place the clamp on sound tooth structure below the carious lesion. Exposed redundant tissue can be tugged back underneath the dam with the same blunt instrument (Figure 3). Another option would be to excise the tissue with a #15 Bard Parker

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blade or electrosurgery. However, excising will induce bleeding and electrosurgery would be a delicate procedure to perform around the jaw of the metal clamp.

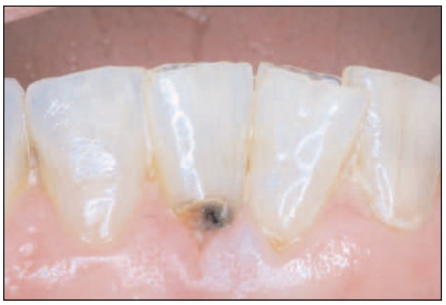


Figure 1. *Pre-operative clinical picture of #25. Note the extensive facial decay underneath the free gingival crest.*

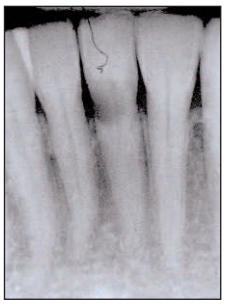


Figure 2. *Pre-operative radiograph of #25 confirming the extensive loss of tooth structure due to decay.*

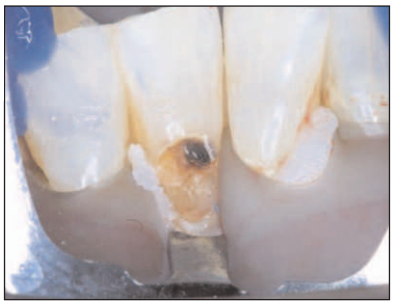


Figure 3. *Completed rubber dam showing location of the 212 clamp. Facial tissue was released by blunt dissection with a cord packing instrument.*

3. Extensive decay dictated the facial location of the 212 clamp. Because of the difficult position, one may position the lingual half of the 212 clamp to rest on a short cotton roll instead of the cingulum of the tooth. The cotton roll helps to alleviate the pressure of the clamp (Figure 4A and B).

4. The field was properly isolated with a retraction clamp. Similar to a technique described by Woodmansey (1998), stabilization of the 212 clamp was achieved with blockout resin (Ultradent Products Inc, South Jordan, UT, USA) underneath the bow of the clamp.

5. Removal of the decay was initiated with a large, round carbide bur followed by checking with hand instrumentation, for example, a spoon excavator. One may also use a caries dye indicator to check for residual caries (Figures 5A and B).

6. The preparation was completed (Figure 6). Because of the proximal extensions, the matrix techniques described by Matis and Cochran (2002) could not be applied.

7. A #1 Adult Universal band (Waterpik Technologies, Inc, Ft Collins, CO, USA) was cut to the desired length. The primary goal was to seal the margins while leaving enough room for access.

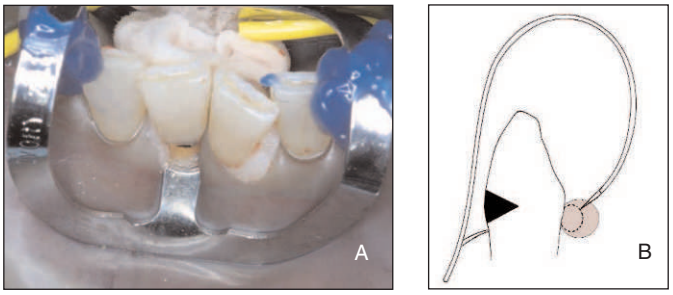


Figure 4*A: Incisal view of the operating field showing stabilization of 212 clamp with blockout resin (Ultradent) underneath the bow of the clamp. 4B: Diagrammatic representation of the position of the 212 clamp resting on a compressed cotton roll instead of the cingulum of the tooth.*

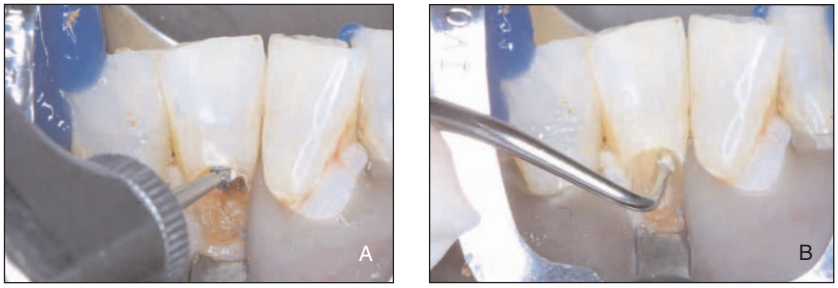


Figure 5 *A and B: Conservative instrumentation sequence with rotary round bur and spoon excavator.*

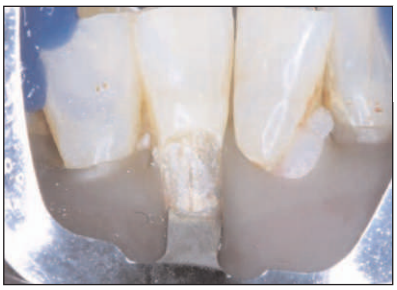
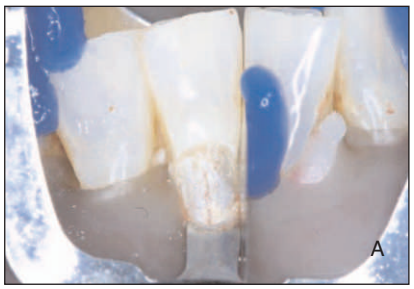


Figure 6*: Completed preparation.excavator.*



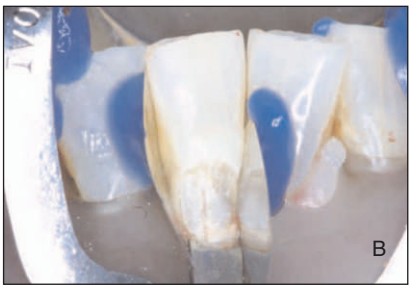


Figure 7*A and B: Sectional matrix with proper proximal and gingival seal.*

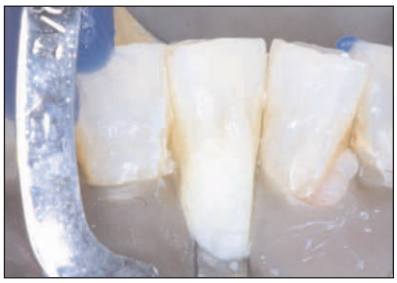
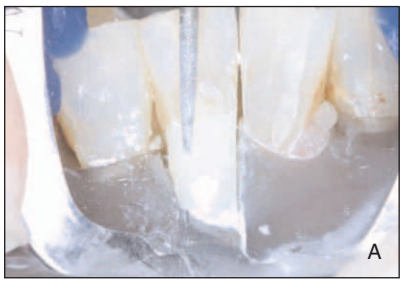


Figure 8*: Restoration with a resin modified glass ionomer.*



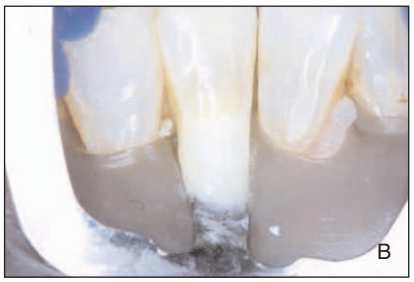


Figure 9*A and B: Finishing and polishing with fine diamonds and Enhance polishing system.*

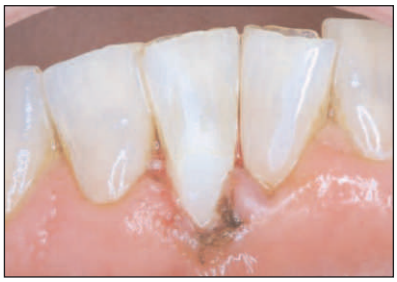
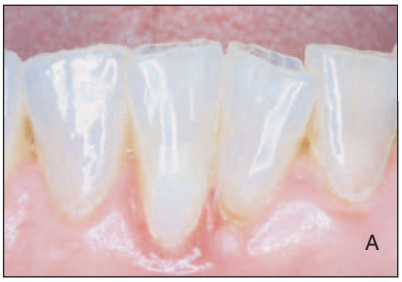


Figure 10*: Immediate post-op after rubber dam removal and refining of the gingival margins.*



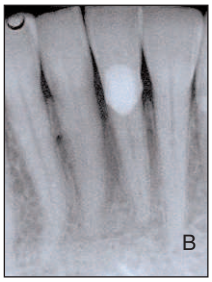


Figure 11*A and B: Post-operative clinical and radiograph of #25. Note the tissue healing after three weeks.*

8. The sectioned #1 band was placed through the contact and a hemostat was used to insert the band firmly towards the gingival margin. A wedge can be applied from the lingual side, if necessary. A visual check was made to confirm that the margins were sealed (Figure 7A). A smaller amount of LC blocking resin (Ultradent Products Inc) was injected onto the outside of the sectioned #1 band and the facial portion of the adjacent teeth. After light curing, the blocking resin provided additional retention and stability.

9. The same procedure was repeated on the distal portion of the cavity (Figure 7B).

10. The prepared cavity was then ready to be restored. A resin-modified glass ionomer (Fuji II LC, GC America, Inc, Alsip, IL, USA) was prescribed. In addition to its fluoride-releasing property, resin-modified glass ionomer also shows a high degree of biocompatibility to the pulp and surrounding soft tissues. (Mount, 1998).

11. After conditioning with GC Cavity Conditioner (Fuji II LC) for 10 seconds, the resin-modified glass ionomer was injected into the deepest portion of the cavity and slowly withdrawn to overfill slightly. A titanium nitride coated instrument was used to "wipe" the material towards the margin. Care should be taken not to condense, since the material is very sticky and may lift off with the instrument, creating internal voids or open margins. The whole increment was light cured for 20 seconds.

12. The bands were easily removed by flicking the LC blockout resin off using a scaler. Then, the whole increment was light cured for an additional 20 seconds. The mesial and distal portions of the restoration were trimmed back to proper contour and anatomy with a #12 Bard Parker blade (Figure 8).

13. The restoration was then contoured with fine diamonds (Brasseler USA, Savannah, GA, USA) under air/water spray (Figure 9A). Final polishing was achieved with the Enhance polishing system (Dentsply-Caulk, Milford, DE, USA) before removing the rubber dam (Figure 9B).

14. Additional refining of the margins after removal of the rubber dam was achieved with ET-burs (Brasseler USA, Savannah, GA, USA). Notice that no major tissue trauma occurred prior to this point (Figure 10). It was necessary to use the ET burs at the gingival margins because the previous position of the clamp prevented adequate finishing of the margins.

15. Post-operative care included gentle massage of the tissue and reinforcement of oral hygiene instructions to bring the area back to health.

16. A post-operative clinical picture and radiograph show good tissue response to the restoration (Figure 11A and B).

SUMMARY

This article outlines an atraumatic isolation approach and a conservative instrumentation sequence, followed by use of a highly viscous, rapid-setting, capsulated glass ionomer cement to manage a difficult deep proximal-cervical Class V lesion.

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Customized and Low-cost Aspirator Device for Intra-oral Sandblasting

EG Reston • LQ Closs • CT Sato

Clinical Relevance

This device helps to reduce aluminum oxide powder in the air when sandblasting during intra-oral procedures, simulating laboratory units.

INTRODUCTION

Adhesive systems mechanisms of action are based on micromechanical retention, either to tooth structure or restorative materials. When bonding a restorative material, the tooth surface must be properly cleaned followed by acid etching to create conditions for a reliable, durable bond. Besides acid etching, sandblasting (or micro etching) with aluminum oxide particles can also create porosities on the surface that have been shown to improve adhesion. Indirect restorations can be easily etched in sandblasting units prior to cementation. Lately, the use of intra-oral sandblasters has become a routine procedure. Intra-oral sandblasting is particularly indicated for:

1) Amalgam repairs (Diefenderfer, Reinhardt & Brown, 1997).

2) Bonding of orthodontic accessories (Canay, Kocadereli & Ak"ca, 2000; Jost-Brinkmann, Drost & Can, 1996; Sonis, 1996; Wiechmann, 2000).

3) Bonding resin composite to ceramic (Shahverdi & others, 1998).

4) Retention and cementation of indirect restorations (Bouschlicher, Cobb & Vargas, 1999; García-Godoy & others, 1991; Hummel & others, 1997; McCaughey, 1993; McIntyre 1995).

The amount of aluminum oxide powder that remains suspended in the air after sandblasting is one of the few disadvantages associated with this technique. This paper describes a simple, low-cost, customized device that allows clinicians to reduce the amount of powder suspension. This device confines the area of application by creating a mini-chamber with an aspirator device connected to it. Because the chamber does not significantly reduce the amount of powder, a saliva ejector tip has been added. This custom-made aspiration device helps by working concurrently with the sandblasting device.

TECHNIQUE

The following description might have to be adapted for each tooth size and arch alignment.

Step 1—Take a film roll canister and make a hole proportionally sized to the diameter of a saliva ejector tip by using any laboratory carbide bur in a handpiece. Dispose of the canister lid (Figures 1 and 2).

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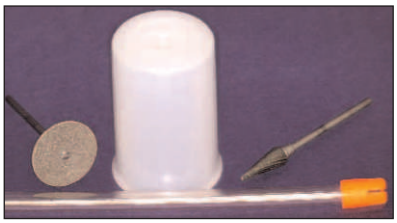

Figure 1*: Film canister, aspirating tip, separating disk and laboratory bur.*

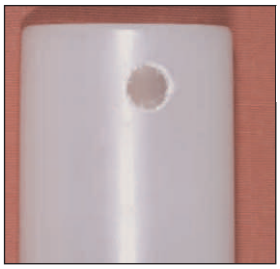

Figure 2*: Lateral perforation for inserting the aspirator tip.*

Figure 2*: Heated silicon glue.*

Figure 4*: Device ready for use. Sandblaster attached to the top small hole and bottom concavities for best fitting in the working area.*

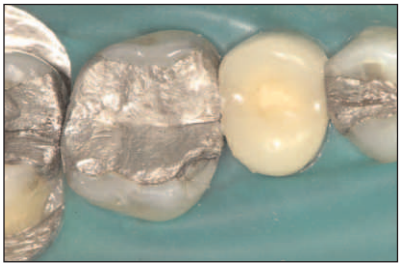

Figure 5*: Pre-operative view after rubber dam placement. Large amalgam restoration with a chipped lingual cusp.*

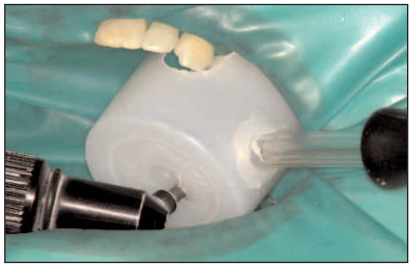

Figure 6*: Device in position with sandblaster ready to etch the area.*

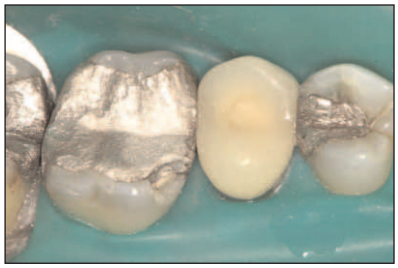

Figure 7*: View of the etched surface.*

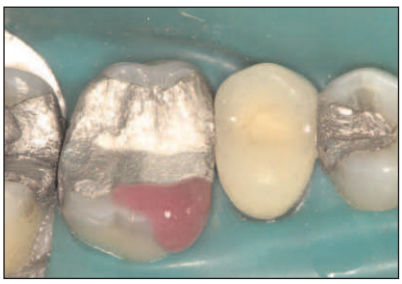

Figure 8. *Acid etch for bonding system application.*

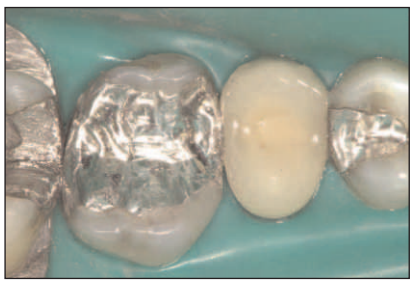

Figure 9. *After resin placement, polymerization and finishing (including polishing of old amalgam restoration).*

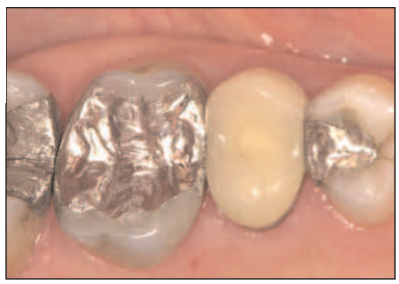

Figure 10*: Post-operative view.*

Step 2—Use heated silicon glue (Figure 3) to seal the interface between the canister and ejector tip. Before the glue sets, insert the aspirating tip inside the hole 2-to-3 mm into the canister.

Step 3—Reduce the height of the canister by using a separating disc according to the maximum mouth opening of your patient.

Step 4—Position the canister inside the mouth and mark both the alignment and the size of the teeth. Take the bur again and trim the area that will adapt to the contour of the teeth.

Step 5—Find the most convenient area to drill a small hole to attach the sandblaster tip. Be careful to gently make the size of the hole smaller than the tip, which will then be attached tightly.

Step 6—Connect the aspirating tip to the aspirating unit and the sandblaster to the device (Figure 4).

Step 7—Place the device so that it covers the selected area. Turn on the aspirating unit and start sandblasting. Be careful not to neglect protective measures.

Step 8—Remove the device, and check if more etching is necessary (if so, repeat steps 6 and 7). Rinse thoroughly to remove the aluminum oxide powder. Dry the field and follow the conventional bonding procedures.

CLINICAL EXAMPLE

A 55 year-old female patient came to an appointment presenting a chipped lingual cusp on tooth # 26 (first upper left molar). Clinical evaluation showed an old, large amalgam restoration with well-sealed margins.

The surface of the restoration revealed a certain degree of corrosion due to the aging of the material (Figure 5). The patient clearly mentioned that she could not afford and did not want an indirect restoration, the best type of restoration for such a case. After explaining to the patient that a repair had its limitations in terms of longevity and resistance, a decision was made. First, the area was isolated with a rubber dam. Then, the device was placed over the chipped tooth (Figure 6). Instead of using burs, sandblasting was performed to increase mechanical retention (Figure 7). The area was then cleaned with acid etching, again to increase retention of the bonding system (Figure 8). A micro hybrid resin composite was selected to repair the area; it was placed in two incremental layers and cured according to instructions provided by the manufacturer (Figure 9). Finishing procedures involved the resin composite and the old amalgam. The occlusion was checked immediately after the rubber dam was removed. It was possible to observe the shiny surface of the amalgam after polishing and adaptation of the repair (Figure 10).

SUMMARY

This paper presents a simple technique that uses a novel device made of low-cost materials and is very helpful in routine clinical activity. This device plays an important role in reducing the suspension of particles in the air when a sandblaster of aluminum oxide powder is used intraorally to create additional micromechanical retention prior to applying a bonded restoration.

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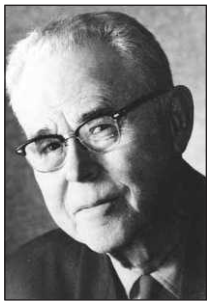
Academy of Operative Dentistry

Hollenback Memorial Prize

Dr Ivar A Mjör



George Hollenback

Ivar A Mjör

It is a great privilege to have been asked to prepare the citation for the winner of the 2004 Hollenback Memorial Prize—Dr Ivar Mjör, Professor of Operative Dentistry and Academy 100 Eminent Scholar, College of Dentistry, University of Florida. Ivar Mjör, notwithstanding being a native of Norway, is one of a rare breed—a truly renowned, international opinion leader and world-class researcher, lecturer, mentor and teacher. Few people have contributed so much new knowledge and understanding to their field of special interest and expertise. In Ivar Mjör's case, the field is remarkably large, including pulp-dentin biology, the biological, physical and chemical properties of dental materials, cariology and, if that were not enough for one man, modern concepts in operative dentistry. With the passage of time, has the quality, quantity and importance of Ivan Mjör's many, varied contributions to research in any way lessened? No! On the contrary, they continue to be maintained and, in many respects, enhanced with his ever-expanding, encyclopedic knowledge and understanding of matters pertaining to the theory and practice of operative dentistry.

Ivar Mjör completed his primary dental degree training at Dundee Dental School, University of St Andrews in Scotland, an excellent foundation for any career in dentistry. He subsequently went on to obtain an MSD degree in Pedodontics and an MS degree in Anatomy from the University of Alabama, followed by a Dr odont degree from the University of Oslo. These qualifications make Ivar Mjör uniquely qualified in the field of operative dentistry. In addition, his distinction and academic excellence have subsequently been recognized with the award of no fewer than eight honorary degrees, all but one of them higher doctoral qualifications.

Ivar Mjör first burst on to the international scene through his research on pulp-dentin biology. His work spanned a number of key areas, including normal structure and tissue reaction in as diverse fields as restorative dentistry and orthodontics. His microradiographic studies on dentin and pulp and electron microscopic investigations of human teeth continue to be referred to extensively in the dental and anatomical literature. Subsequent work provided a new understanding of the reaction potentials of dentin in recently erupted teeth, the branching of dentinal tubules, the healing of localized abscesses in pulp and many other essential features of the pulp-dentin organ. This element of Ivar Mjör's research forms the basis of the latest of his eight highly acclaimed textbooks, *Pulp-Dentin Biology in Restorative Dentistry*, published in 2002.

With his appointment as Director of NIOM, the Scandinavian Institute of Dental Materials, a position Ivar Mjör moved to from his prestigious appointment as Professor of Dentistry and Chairman of the Department of Anatomy in the Dental Faculty, University of Oslo, he strengthened his international standing through his world-class work on the biological, physical and clinical properties of dental materials. At the same time he remained research active in the fields of pulp-dentin biology and cariology, and among a number of other

demanding positions, he was Editor-in-Chief of *Acta Odontologica Scandinavia* over a period of 15 years.

More recently and, in particular, following his move to the College of Dentistry, University of Florida, Ivar Mjör has focused increasingly on clinical and related health services research; projects on, for example, reasons for the placement and replacement of restorations having been conducted and emulated around the world. The theme running through this important aspect of his lifelong endeavors in research is the need for practice-based research capable of yielding "real world" data. This is a topic that Ivar Mjör writes about and lectures on with great passion.

Among a veritable galaxy of honors and awards, Ivar Mjör has been President of the Norwegian Dental Association and the International Association of Dental Research. He is an honorary member of a number of national dental associations, including the American Dental Association and numerous other dental organizations. The Hollenback Prize, the Academy's highest award for achievement in research, is, however, an accolade that has eluded him to date.

What about the man behind all the great science and academic achievement? Behind the ever youthful, charismatic exterior is a tough, time-tempered personality. As he puts it, "My skin is so thick I could stay standing without a spine." He sees and describes things the way that they are; he is meticulous in what he does and enjoys a robust defense of his views, many of which have been controversial, at least until his critics come round to seeing things from the Mjör point of view!

Ivar Mjör richly deserves the Hollenback Memorial Prize. As a giant among his fellow researchers, he epitomizes the spirit of the Prize—selfless commitment to the advancement of knowledge and understanding and, in turn, improved oral healthcare for patients around the world. The Academy is greatly honored to have Ivar Mjör as the winner of the 2004 Hollenback Memorial Prize.

Nairn HF Wilson

Academy of Operative Dentistry
Award of Excellence
Dr Norm C Ferguson

It is an honor to present the Academy of Operative Dentistry's 2004 Award of Excellence to Dr Norman C Ferguson. Dr Ferguson graduated from North Pacific College, Portland Oregon, in 1944, and married his wife Frances two years later. Dr Ferguson, or Norm as his friends like to call him, practiced dentistry for nearly 60 years. During these years he has made many outstanding accomplishments in the profession.

He mentored two study clubs in gold foil, mentored two study clubs in high fusing all porcelain crown techniques and mentored one study club in cast gold restorations. Norm is also the longest serving clinical associate professor in the University of British Columbia's faculty of dentistry. Although he is most known for his expertise in gold foil restorations and cast gold restorations, he has also completed extensive clinical research concerning the treatment of diastema in young patients. He has developed a unique procedure to close maxillary anterior diastema between the central incisors without the need for braces, by removing the labial frenum at exactly the right time. Not only can he reliably determine which diastemas will not close on their own, but he has also "proved" the efficacy of his treatment technique by sequentially treating identical twins with diastemas to demonstrate the direct correlation of treatment to diastema closure.

In his research on occlusion, Dr Ferguson has discovered a unique movement of the mandible on the maxilla known as the "Ferguson Rock." This condition is present in all Class I occlusions that have not been treated orthodontically and is typified by occlusal contact in the area of the bicuspids with light occlusal forces and contact of the molars only under heavy occlusal loads. This change in occlusal contacts during loading compensates for compression of the temporomandibular joint.

Norm has lectured in Canada, the United States, Japan, China, Germany and England, speaking on the subjects of Occlusion, Cast Gold Restorations, Gold Foil Restorations, Porcelain Restorations and Diastema Closure. He has also published papers on the topics of Occlusion, Frenum Closure, Office Lighting and Magnification for Dentists.

Norm C Ferguson

Norm has received many honors for his dedication to dentistry. He is a member of OKU and has fellowships in the Royal College of Dentists of Canada, the American College of Dentists, the International College of Dentists and the Academy of Dentistry International. He is a member of the American Academy of Restorative Dentistry, the Academy of Operative Dentistry, the Canadian Academy of Restorative Dentistry and Prosthodontics and the American Academy of Gold Foil Operators, serving as president in 1983.

Norm continues to amaze people who engage him in a "casual" conversation with his depth and breadth of knowledge on subjects ranging from Latin and History to Dentistry and Humanity. One typical conversation went like this, "Of course, you know why Dr Lloyd Jacobson's amalgam restorations lasted so long. He used a mix of silver and mercury that contained excess mercury. The tin in the mix, which was added to improve trituration, is more soluble in the mercury. Then, as Dr Jacobson filled the tooth with the amalgam, he worked the excess mercury out of the mix, carrying the tin with it. He even used pliers to squeeze out the last bit of excess mercury and, perhaps unknowingly, also removed the tin in the mix that was responsible for the gamma two phase that leads to corrosion." He is a truly remarkable person, a fountain of knowledge and continues to be an inspiration to us all.

President Stevenson, members of the Academy of Operative Dentistrys and guests, it is my honor and privilege to present to you Dr Norman C Ferguson, this year's recipient of the Academy of Operative Dentistry's Award of Excellence.

Richard D Tucker

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The Department has an active and strong research culture and the major areas of focus include the development and characterization of biomaterials, clinical evaluation of new restorative materials and dental implants. Staff are also involved in the supervision of graduate local and international research students for Master's and PhD programs. There is active collaboration with other faculties and institutions to achieve our research goals.

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