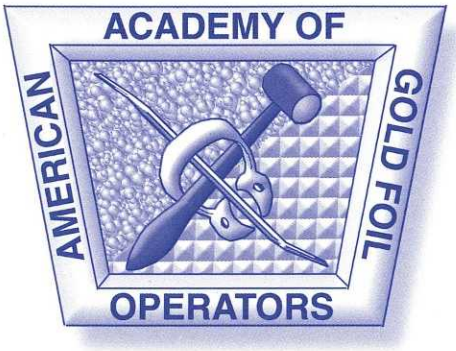
OPERATIVE DENTISTRY



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Aim and Scope

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

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Guest Editorial

Operative Dentistry: The First Twenty-Five Years

The journal *Operative Dentistry* began 25 years ago under the joint ownership and sponsorship of the Academy of Operative Dentistry and the American Academy of Gold Foil Operators. *Operative Dentistry* was to be a new journal. Its purpose was to advance the practice of operative dentistry—its art, its science and its craft. Dr A Ian Hamilton was selected to be the first editor. It was under his direction and supervision that the foundation for this excellent scientific and clinical journal was organized. The task of starting a new journal was formidable and time-consuming. In his quest for excellence in dental journalism, Dr Hamilton put in long and rigorous hours. Every detail, from page layout to copyright security, came under his direct supervision. The editorial assistants, managing editor, editorial board, referees, typesetters, book reviewers, copy editor and selection of a reasonable printer for the *Journal* were just a few of the items under his aegis. These organizational details were difficult enough, but in retrospect, they were small potatoes compared to the tasks that lay ahead: getting good articles for publication and then getting those articles in the best shape possible for the readers.

Adlai Stevenson once said, "Editors are very good at separating the wheat from the chaff, and then they print the chaff." During my years of working with the editors of *Operative Dentistry*, I got a kick out of how they liked to prune articles. Certain words and phrases were forbidden. Sometimes whole paragraphs were cut; sometimes whole articles rewritten. For example, Dr Hamilton did not allow "impact" on his pristine pages, unless it referred to an airplane crash or the striking of one body against another. Adverbs were permitted: sparingly. "Arguably" was cleanly excised; no floating "whatevers" were allowed and most "indeeds" at the beginning of sentences were lopped away. "Incredible" and "fascinating" were relegated to the circus barkers. The qualifiers "rather," "very," "pretty," and "somewhat" were cut, as was "intriguing," except when it referred to plotting and spying. "Little" could be used only to indicate size. Heaping modifiers all in a row were not allowed. Anything that smacked of psycho-jargon or cant was out, which included "special," "caring," and "sharing." Academic locutions took a brutal beating: very few "in terms of" got by, fewer "as it were" and no "if you will's" whatsoever; the Latin abbreviations "i.e.," "e.g." and "etc." were sent to the woodshed. The result: clear, understandable writing.

Each *Operative Dentistry* editor had to reject a fair number of articles submitted for publication because the information presented was either redundant or not significantly useful. Journal editors are, of course, the stewards of scientific quality, and they face a very difficult task. In most scholarly research, and in the digging out and reporting of news, "fact" means "true." No journal can afford to publish all the evidence required to support an author's experimental conclusions. But, how can an editor approve publication when information necessary to proof is missing? What if the experiment and research is incomplete or erroneous? An all too frequent comment at the conclusion of an article is that "more research is needed." It would be better to *conduct* the needed research, *then* publish the results. The reader has to trust the author and the editor to invoke those procedures properly. Thus, one's reputation for trustworthiness, call it intellectual integrity, if not honesty, is crucial to a scientific journal. Concerns about scientific integrity permeate every piece of research that is done, every talk we hear, every paper we read. The reader of *Operative Dentistry* deserves high quality articles.

Throughout its 25-year history, the *Journal* has published essays, opinions and viewpoints by editors and guests. These essays are of great importance because they bring ideas and criticisms to the fore. For example, many editorials have described the plight of dental education in Operative Dentistry.

Editorials have expounded on the difficulty in recruiting, training and retaining excellent teachers in our dental schools. Essayists have elucidated the plight of dentists overwhelmed by the marketing departments of dental manufacturers. Point-of-view articles have described the ethical difficulties dentists face with a profession that must bear the tactics of insurance companies. Papers have been written explaining how dental school curriculums in operative dentistry have been eroded and undermined by naive administrators. At least one article gazed gleefully into the future in an attempt to illuminate a perspective of probable changes in the profession. Quality of care has been frequently discussed and will likely continue to be investigated.

In publishing these editorials and commentaries, *Operative Dentistry* has brought the reader information vital for the health of the profession and the success of clinical practice. Critical commentary is an essential ingredient in advancing the art, science and the craft of

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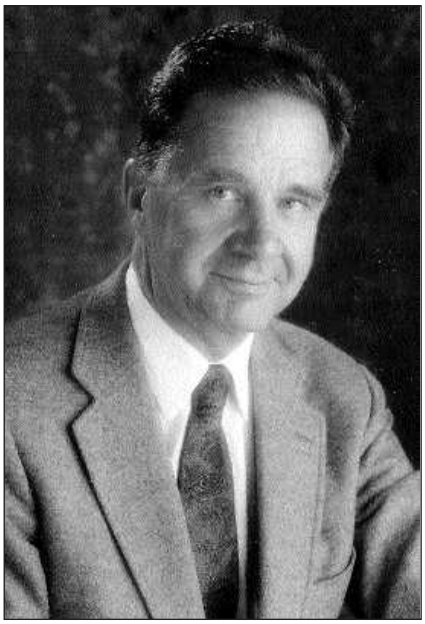

J Martin Anderson

By reviewing the dental literature over the past 25 years, viewing the current state of dental education (undergraduate, post-graduate and that obtained in the trade magazines and one-day courses) and by contemplating the nature of restorations currently being placed by clinicians, one can opine that we need to temper our optimism and self-assurance: progress is not inevitable in any field, especially the very technical Operative Dentistry.

I feel very fortunate and privileged to have served as Managing Editor of *Operative Dentistry* for the past 25 years. I will always be indebted to the editors under whom I have served: A Ian Hamilton, David J Bales, Maxwell H Anderson and Richard B McCoy. Each editor has left his mark of excellence on the *Journal*. Each has served selflessly. Each has lifted the quality of dental journalism.

As the new millennium begins, the *Journal* has a new home at the Indiana University School of Dentistry under the new Editor, Michael A Cochran and his Managing Editor, Timothy J Carlson. The challenges that face the new administrators of our excellent dental journal will be formidable but, in my opinion, very exciting. I give them my best wishes and eternal support.

J Martin Anderson
University of Washington, School of Dentistry

Commentary

Marty Anderson is an amazing man. As managing editor of the journal *Operative Dentistry* during its first 25 years, he has donated more hours ensuring the success, excellence and integrity of our publication than any other individual. It is the responsibility of the managing editor to oversee subscriptions, income and disbursements, and to work in the background to make sure the important work of the authors and editors makes its way into the hands of the readers in an efficient manner. To Marty it has been a labor of love. He has many interests that he pours himself into: full-time dental practice, part-time dental faculty, family, restoring automobiles, managing the *Journal* and many others; all done with a zest for excellence and a modesty that belies his expertise.

I first became acquainted with Marty as he gave *Journal* reports at the Operative Academy meetings. Later as a Counselor, I was impressed by the professional way he handled the financial affairs and details of publishing the *Journal*. Many years were undoubtedly difficult, as the editorial team continued to grow the significance and size of the publication while working with a very limited budget. Through four fine editors, Marty saw the *Journal* grow from 160 pages per year in four issues in 1976 to 390 pages in six issues when he completed his 25th continuous year as managing editor in 1999.

It has been a personal joy and privilege working with Marty and his Subscription Manager, Judy Valela to transfer the editorial and business offices of the *Journal* to Indiana. The editorial team in Seattle, headed by Dick McCoy and Marty Anderson, was extremely helpful in making a smooth transition to Indiana. Marty even volunteered to remain at his post for several months after the completion of his term in order to process the rush of subscriptions which occurs each spring.

Creating and developing a scientific journal must have some similarities to raising a child. There are concerns about adequate support, nurturing and future planning. There are innumerable details that need attention. There are frustrations, setbacks and late nights, yet joy at seeing others appreciate the outcome as it develops over time. As it grows and develops, one has invested much, and it is bittersweet when the *Journal* or the young adult is mature enough to leave home. One can be proud that the significant investment of time and effort has contributed to such a fine result.

Mike Cochran and I, our subscription manager Joan Matis, and the entire *Operative Dentistry* readership are indebted to you, J Martin Anderson, for your tireless effort in carrying the *Journal* forward. Thank you for your expertise and advice, as together we look forward to a bright future for our *Journal.*

Timothy J Carlson,
Managing Editor

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Clinical Research

Leucite-Reinforced Glass Ceramic Inlays and Onlays After Six Years: Clinical Behavior

R Frankenberger • A Petschelt • N Krämer

Clinical Relevance

Adhesively luted IPS Empress inlays and onlays showed an acceptable clinical behavior, exhibiting a 7% failure rate after six years of clinical service.

SUMMARY

Ceramic inlays are an esthetic substitute for large amalgam and other metallic restorations. This controlled clinical study evaluated the performance of IPS Empress inlays and onlays with cuspal replacements and proximal margins below the cementoenamel junction over six years of clinical service.

Six dentists placed 96 ceramic restorations in 34 patients. Luting was accomplished using the enamel-etch-technique, a dentin bonding system (Syntac Classic) and four different composite systems. The restorations were assessed by two calibrated investigators using modified USPHS criteria at baseline (96 restorations), one (96), two (95), four (89) and six years (67).

Seven of the 96 restorations investigated had to be replaced (failure rate 7%; Kaplan-Meier): Five inlays suffered cohesive bulk fractures and two teeth required endodontic treatment. After six years of clinical service, significant deterioration (Friedman 2-way ANOVA; $p<0.05$) was found for marginal adaptation of the remaining restorations. Ninety-four percent of the surviving restorations exhibited marginal deficiencies, independent of the luting composite. Neither the absence of enamel margins, nor cuspal replacement significantly affected the quality of the restorations.

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INTRODUCTION

In recent years various dental ceramics have been developed and clinically investigated (Jäger, Wirz & Schmidli, 1990; Banks, 1990; Kelly, Nishimura &

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Campbell, 1996; Qualthrough & Piddock, 1997; Thonemann & others, 1997). One very popular ceramic is the leucite-reinforced glass ceramic IPS Empress, which was introduced in 1990 (Wohlwend & Schärer, 1990; Studer, Lehner & Schärer, 1992; Fradeani, Aquilano & Bassein, 1997; Krämer & others, 1999).

Generally when dealing with ceramic inlays and onlays, bulk fractures have been observed with all-ceramic systems on the market (Molin & Karlsson, 1996). In addition, few controlled prospective clinical studies are available to provide evidence about long-term performances of different systems (Walther, Reiss & Toutenburg, 1994; Fuzzi & Rappelli, 1998; Fuzzi & Rappelli, 1999).

Despite adhesive luting, sintered ceramics exhibited fractures in up to 20% of clinically-assessed cases and failures occurred at various times during service. Large Class I restorations tended to show marginal fractures, while in Class II inlays, bulk fractures have reportedly been the predominate failure scenario (Molin & Karlsson, 1996; Qualthrough & Wilson, 1996). However, certain clinical investigations were characterized by low failure rates *in vivo* (Höglund, van Dijken & Olofsson, 1994; Thordrup, Isidor & Hörstedt-Bindslev, 1994). Inlays made of the glassfiber-reinforced ceramic system Mirage II (Chameleon Dental Products, Kansas City, USA) revealed no failures after two years of clinical service (Friedl & others, 1996). Dicor (Dentsply DeTrey, Konstanz, Germany) glass ceramic inlays were also found to exhibit high success rates (>95%) (Bessing & Molin, 1990; Stenberg & Matsson, 1993; Gladys & others, 1995; Roulet, 1997; Hayashi & others, 1998). Similar data have been published for the leucite-reinforced ceramic system IPS Empress (Ivoclar, Schaan, Liechtenstein) (Krejci I, Krejci D & Lutz, 1992; Reinelt & others, 1995; Studer, Lehner & Schärer, 1992). There is also considerable documentation for CAD/CAM ceramic restorations (Heymann & others, 1996; Isenberg, Essig & Leinfelder, 1992; Mörmann & Krejci, 1992; Sjögren & others, 1995). These reports give positive ratings for fracture resistance. Reiss evaluated 1011 Cerec (Vita Mark II, Vita Zahnfabrik, Bad Säckingen, Germany) inlays over a period of nine years with a 3% fracture rate (Reiss & Walther, 1998). Walther computed a survival analysis of 95% after five years as being representative of other Cerec investigations (Isenberg, Essig & Leinfelder, 1992; Mörmann & Krejci, 1992; Reiss & Walther, 1998). However, all clinical studies dealing with ceramic inlays reveal distinct marginal deterioration of the restorations (Gladys & others, 1995; Heymann & others, 1996; Molin & Karlsson, 1996; Qualthrough & Wilson, 1996; Friedl & others, 1997).

This clinical long-term trial evaluated the performance of adhesively luted extensive IPS Empress inlays and onlays with margins partially located below the cementoenamel junction.

METHODS AND MATERIALS

Patients were selected for this study based on the following criteria:

1) Absence of pain from the tooth to be restored.
2) Possible application of a rubber dam.
3) Proximal margins located below the cementoenamel junction in 50% of the cases, if possible.
4) No further restorations planned in other posterior teeth.
5) A high level of oral hygiene.
6) The absence of any active periodontal and pulpal disease.

All patients were treated in the Policlinic for Operative Dentistry and Periodontology, University of Erlangen-Nuremberg, Germany, by six clinicians (assistant professors) experienced with placing ceramic inlays and onlays. All patients gave their written informed consent. The study was conducted according to EN 540 (Clinical investigation of medical devices for human subjects, European Committee for Standardization). The patients agreed to a recall program of four years consisting of one appointment per year. The six-year recall was voluntary.

The preparations for the restorations were done with appropriate taper without bevelling of the margins using 80 µm diamond burs (Inlay Prep-Set, Intensiv, Viganello-Lugano, Switzerland), and finished with 25 µm finishing diamonds. The minimum depth of the cavity was 1.5 mm, with rounded occluso-axial angles. Dentin close to the pulp was covered with a calcium-hydroxide cement (Calxyl, OCO-Praeparate GmBH, D-67246 Dirmstein, Germany). A glass-ionomer cement (Ketac Bond, ESPE, Seefeld, Germany) was used as the lining material.

Full-arch impressions were taken using a polyvinyl-siloxane material (Permagum High Viscosity, ESPE, Seefeld, D-82229 Germany) and a low-viscosity material (Permagum Garant, ESPE, Seefeld, Germany) in syringes was used to record preparation details.

One dental ceramist fabricated all the inlays and onlays according to the manufacturer's instructions.

The intraoral fit was evaluated under rubber dam. Internal adjustments were performed using finishing diamonds. Interproximal contacts were assessed using waxed dental floss and special contact gauges (YS Contact Gauge, YDM-Yamaura, Tokyo, Japan). The thickness of the inlays and onlays was recorded prior to insertion using a pair of tactile compasses (Schnelltaster, D-36381 Kroeplin, Schluechtern, Germany) with an accuracy of .01 mm. The minimum

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thickness between the deepest fissure and fitting surface, minimal width in the isthmus region for inlays and the minimum thickness of the cuspal coverage in onlays were measured.

The inlays were luted adhesively under rubber dam and the enamel etch technique was used. The prepared teeth were thoroughly cleaned with pumice slurry and etched with 37% phosphoric acid gel. The dentin adhesive system Syntac Classic (Vivadent) was then applied. The internal surface of the restorations were etched with 4.5% hydrofluoric acid (IPS Ceramic etching gel, Vivadent, Schaan, Liechtenstein) for 60 seconds, rinsed, then silanated with Monobond S (Vivadent). After applying the silane coupling agent, the solvent was evaporated with compressed air.

Adhesive insertion was performed with four different luting composites: Dual Cement (n=9), Variolink Low (n=32), Variolink Ultra (n=6) and Tetric (n=49) (all Vivadent, FL9494 Schaan, Liechtenstein). The composite resins with high viscosity (Variolink Ultra, Tetric) were used according to the USI-technique (ultrasonic insertion/EMS Piezon Master 400, Le Sentier, Switzerland) utilizing the thixotropic properties of the resin composite materials (Noack, Roulet & Bergmann, 1991). Polymerization of the luting agents was performed by light curing for a total of 120 seconds from different positions (40 seconds in each direction). Prior to polymerization, the luting composite was covered with glycerine gel to prevent the formation of an oxygen-inhibited layer.

Table 1: *Features of the Restorations Investigated*

surface roughness
color matching
anatomic form
anatomic form (margin)
marginal integrity
integrity tooth
integrity inlay
proximal contact
changes in sensitivity
complaints
radiographic check
subjective contentment

Table 2: *Modified USPHS Criteria*

modified criteria	description	analogous USPHS criteria
"excellent"	perfect	"alpha"
"good"	slight deviations from ideal performance, correction possible without damage of tooth or restoration	
"sufficient"	few defects, correction impossible without damage of tooth or restoration.No negative effects expected	"bravo"
"insufficient"	severe defects, prophylactic removal for prevention of severe failures	"charlie"
"poor"	Immediate replacement necessary	"delta"

After light curing and examining the luting areas for defects, the rubber dam was removed. Centric and eccentric occlusal contacts were adjusted using diamond finishing burs (Intensiv, Viganello-Lugano, Switzerland) prior to Sof-Lex discs (3M, St Paul, MN, USA). Overhangs were removed and polished in the same way, proximally with interdental diamond strips (GC Dental Industrial Corp, Tokyo, Japan) and interdental polishing strips (3M, St Paul, MN, USA). Final polishing was conducted using felt discs (Dia-Finish E Filzscheiben, Renfert, D-78247 Hilzingen, Germany) with polishing gel (Brinell, Renfert D-78247 Hilzingen, Germany).

Following placement of a restoration, the restored tooth was covered with a fluoride solution for 60 seconds (Elmex Fluid, Wybert, Lörrach, Germany).

At initial recall (baseline) and after one, two, four and six years, all restorations were assessed according to modified United States Public Health Service (USPHS) criteria (Tables 1 and 2) by two independent investigators using mirrors, probes, bitewing radiographs and intraoral photographs. Recall assessments were not performed by the clinician who originally placed the restorations.

The statistical analysis was computed with SPSS (SPSS Inc, Chicago, IL 60611) for Windows 95/V7.5. The statistic unit was one ceramic restoration, differences between the groups were evaluated pair-wise with the Mann-Whitney test (level of significance 0.05).

RESULTS

Ninety-six inlays (F_2=OD/MO: n=45; F_3=MOD: n=27) and onlays (n=24) were placed in 34 patients (11 male, 23 female; age 20-57 years, mean 33 years). Thirty percent of the restorations were placed (n=29) in maxillary molars, 23% (n=22) in maxillary premolars, 29% (n=28) in mandibular molars and 18% (n=17) in mandibular premolars.

The recall rate until the four-year investigation was 100%, then decreased to 70% due to the voluntary character of the six-year recall. The majority (96%) of the patients were satisfied with their restorations. One patient was dissatisfied due to the marginal fracture of one restoration. Twenty-nine restorations could not be examined after six years due to failure (seven) and missing investigation (22=dropout, patient not available). Throughout the observation period, the other 67 investigated restorations revealed no statistically significant differences regarding surface roughness, color matching, anatomic form, anatomic form (margin), proximal contact, sensitivity, com-

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Table 3: *Results of the Clinical Investigation (1=excellent, 2=good, 3=sufficient)*

investigation [assessed cases]	baseline [89]	1 year [96]	2 years [95]	4 years [89]	6 years [67]
date of investigation (SD)	0.5 years (0.14)	1.1 years (0.16)	2.1 years (0.17)	4.0 years (0.14)	6.0 years (0.33)
surface	1:92% 2:8%	1:41% 2:59%	1:41% 2:59%	1:45% 2:55%	1:84% 2:16%
color matching	1:84% 2:16%	1:59% 2:39% 3:2%	1:66% 2:33% 3:1%	1:75% 2:23% 3:1%	1:92% 2:8%
anatomic form	1:66% 2:34%	1:7% 2:23%	1:74% 2:25% 3:1%	1:53% 2:47%	1:91% 2:9%
anatomic form (margin)	1:43% 2:57%	1:15% 2:85%	1:11% 2:88% 3:1%	1:5% 2:94% 3:1%	1:18% 2:81% 3:1%
proximal contact	1:85% 2:15%	1:87% 2:13%	1:84% 2:10% 3:6%	1:88% 2:11% 3:1%	1:94% 2:6%
changes in sensitivity	1:94% 2:6%	1:94% 2:6%	1:100%	1:100%	1:100%
complaints	1:87% 2:13%	1:90% 2:6% 3:4%	1:98% 2:2%	1:100%	1:100%
radiographic check	----------	----------	1:88% 2:11% 3:1%	1:92% 2:5% 3:3%	1:100%
subjective contentment	1:100%	1:100%	1:99% 3: 1%	1:96% 3:4%	1:100%

plaints, radiographic check and subjective contentment (Table 3).

Comparing the data collected at the recall appointments, significant differences were found for marginal integrity. The rating "excellent" dropped from 39% at baseline to 4 % after six years. The main reason for the "good" judgement was initially "composite overhang," and over time, "marginal ditching" and "discoloration." No statistically significant differences were attributable to the different luting systems ($p<.05$, Mann-Whitney test). One case exhibited a gap formation (adhesive failure between enamel and luting composite) being detected after a cusp fracture.

The absence of enamel in proximal boxes had no influence on marginal performance or secondary caries of the inlays and onlays.

Regarding tooth integrity, significant differences were detected between the baseline and the four-year and six-year recall data. After six years, 66% of the restored teeth included small enamel cracks representing an increase of 50% from the time of insertion of the restorations. Twelve percent of the restored teeth showed enamel crack formation after insertion of the restoration.

Inlay fracture increased over time from 4% at baseline, to 19% after four years and 40% after six years. Chipping in the occlusal-proximal contact areas was mainly observed. Accurate comparisons of clinical photographs revealed that these fractures mainly occured in areas subject to occlusal adjustments.

Prior to the six year recall, seven inlays had to be replaced. The survival rate computed with the Kaplan-Meier algorithm was 93% after six years (Figure 1). Two inlays had to be removed due to complaints (two because of hypersensitivity, one was censored after apex resection prior to the start of the study). Fracture of the ceramic material led to replacement of five inlays. Initial clinical fractures were observed after three years.

The average dimensions measured prior to insertion have been 1.4 mm below the deepest fissure, 3.5 mm orovestibularly at the isthmus and 2.0 mm below reconstructed cusps of onlays. There was no statistically significant correlation between dimensions of the inlay and observed fractures ($p>.05$).

DISCUSSION

This study investigated the six-year performance of adhesively-luted IPS Empress ceramic inlays and

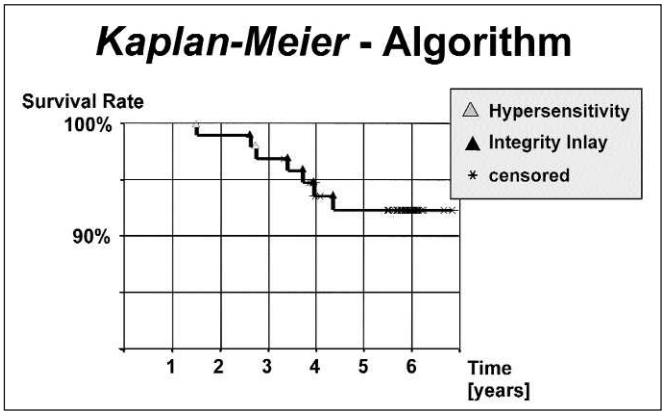

Figure 1. *Survival Analysis (Kaplan-Meier Algorithm)*

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onlays. Particular attention was directed to restorations with proximal margins located in dentin.

The modified USPHS criteria (Cvar & Ryge, 1971) proved to be reliable for the tooth-colored restorations as previously reported by Pelka & others, (1994).

Patient complaints diminished over the course of the study and hypersensitivity was observed in 13% of the cases at baseline, but reduced rapidly. For tooth-colored inlays especially, postoperative hypersensitivites have been reported to be still problematic due to possibly incomplete sealed dentin or detachment between lining material and dentin (Hickel, 1990). Therefore, today, using dentin bonding agents and luting composites is recommended. This study used the dentin adhesive system Syntac Classic with different luting composites of the same manufacturer. Compared with previous studies, the additional use of the dentin bonding led to limited hypersensitivity over the observation period, independent of the composite resin used for luting (Hickel, 1990). After one year, one patient (having received four inlays) reported occasional complaints (rated clinically "sufficient"). During the observation period two inlays had to be replaced due to severe pulpal pain.

To date, numerous clinical studies have assessed the luting space of tooth-colored inlay systems. The majority of the restorations documented were luted with resin composites characterized by low viscosities (Jensen, 1987; Isidor & Brøndum, 1995; Heymann & others, 1996; Rehkugler, Hofmann & Klaiber, 1996). Generally, wear resistance of luting composites has been looked at with skepticism, irrespective of the inlay material (Krejci, Lutz & Reimer, 1994; Kawai, Isenberg & Leinfelder, 1994). Therefore, considerable hopes of enhanced wear resistance had been placed on improvements in luting composites (O'Neil, Miracle & Leinfelder, 1993; Krämer, Pelka & Petschelt, 1995; Roulet & others, 1997; Krämer & others, 1999). However, this study's clinical data does not support the expectations for improved abrasion resistance of higher filled luting composites. For the criterion "marginal integrity," no clinically noticeable difference was noted between the luting agents used. The predominant ratings "good" and "sufficient" after six years were due to contact-free wear inside the luting areas characterized by ditching having been detected in all groups. However, clinical evaluations may be insufficiently accurate for detecting differences of the small luting space.

Insufficient adhesive performance of the bond between restorative material and tooth substrates is another reason for failure of adhesive restorations. van Dijken reported frequent marginal fractures of ceramic inlays luted with glass ionomer cements (Höglund, van Dijken & Olofsson, 1994; van Dijken & Hörstedt, 1994). In this study, marginal fractures were not observed. The uncompromising treatment of the internal ceramic surface (etching and silanating) may have produced minimal material loss and reduced micro-cracks in the internal surface (Qualtrough & Wilson, 1996; Qualtrough & Piddock, 1997; Krämer & others, 1999).

Another concern is the durability and predictability of adhesion to dentin. Warnings against bonding to cervical dentin are well-documented (Schmalz, Federlin & Geurtsen, 1994). However, 30% of the inlays in this study had proximal margins located below the cementoenamel junction, with none of the restorations revealing lower clinical ratings or significant findings, such as secondary caries radiographically.

A further argument for dentin bonding is the estimation that the accurate use of this additional bonding may prevent fractures of the ceramic in bulk or along margins. This tends to confirm the assumption that a larger area of adhesion may enhance the stability of the ceramic (Qualthrough & Wilson, 1996).

Significant differences were detected on enamel surfaces adjacent to restorations. However, these enamel fractures had no significance on the clinical survival behavior of the restorations. About 16% of the enamel cracks (integrity tooth "good") were already recognized at baseline. At six years, this observation increased to 66%. However, no restoration had to be replaced due to these cracks.

"Half-moon" fractures in the restorations were detected as early as two years for the criterion "integrity inlay." These fractures were exclusively observed in occlusally-loaded marginal ridges with pronounced convexities in the direction of the approximating tooth. Analyzing the clinical photographs resulted in finding that in each case of catastrophic failure, occlusal corrections had been performed and this trend continued throughout the study. Over the six years of the study, five inlays failed for this reason. However, bruxism was considered to be associated with the fractures in two cases. Since the four-year report, one restoration had to be replaced because of fracture (Krämer & others, 1999).

A correlation between material or cusp reconstruction thickness and ceramic fractures could not be evaluated. The lowest cusp thickness was recorded 0.3 mm without having any clincial consequences. This indicates that most of the fractures were attributed to fatigue mechanisms. Due to the unfavorable intraoral situation, occlusal corrections normally producing micro-cracks may not have been sufficiently polished. Graf et al reported considerably lower flexural fatigue limits of dental ceramics after simulating occlusal corrections (Graf & others). Therefore, combined with occlusal stress, the probability of ceramic fractures seems to be increased. Nevertheless, to prevent this

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problem, the clinician should carefully polish inlay areas that have been subjected to occlusal corrections.

CONCLUSIONS

- IPS Empress restorations revealed a 7% failure rate, with 94% of the remaining restorations having marginal deficiencies after six years.
- The evaluated restorative system achieved satisfactory results for the restoration of larger defects in molar regions.
- Neither cusp reconstruction nor preparation margins below the cementoenamel junction were limiting factors for good clinical success.
- Secondary caries did not occur.

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Leucite-Reinforced Glass Ceramic Inlays After Six Years: Wear of Luting Composites

N Krämer • R Frankenberger

Clinical Relevance

The wear of a conventional low-viscosity luting composite was similar to a minifilled hybrid resin composite restorative material used for luting of ceramic inlays after six years of clinical service.

SUMMARY

Wear of luting composites is still an unsolved problem with adhesive inlays. However, only limited clinical research has been conducted regarding this phenomenon. This study evaluated the substance loss within the luting gap over a six-year period in vivo**. In the course of a controlled prospective clinical study, 16 patients received 39 Class-II IPS Empress inlays. Variolink Low (Vivadent; n=18) was used as conventional low-viscosity luting composite, the hybrid-type restorative resin composite Tetric (n=21; Vivadent) was applied according to the ultrasonic insertion technique. The restorations were clinically assessed after 6, 12, 24, 36, 48 and 72 months and replicas were made. The contact-free occlusal areas of the replicas were scanned by use of a computer-controlled profilometer (Perthen S3P), the analysis of the data was computed using a newly developed software (Xpert for Windows 95) and statistically analyzed with non-parametric tests. After six months all restorations exhibited marginal ditching. The percentage of detectable luting gap abrasion increased between each recall appointment (32% after six months, 48% after 12 months, 46% after 24 months, 55% after 36 months, 59% after 48 months and 65% after 72 months). Except for the 48-months results, no significant difference between the materials used for luting was evident (p>0.05). Between the width and the depth of the luting space a linear regression was computed. The quantitative evaluation clearly demonstrated that hopes of relevantly reduced wear of luting composites were not confirmed when using the higher filled luting material.**

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INTRODUCTION

Numerous clinical studies report considerable wear within the luting gap of bonded inlays relative to adjacent structures, such as enamel and ceramic or resin

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composite (Krejci & others, 1993; Heymann & others, 1996). The impact of this abrasion phenomenon is considered a major problem with bonded inlays (Krejci & others, 1993; Krejci & others, 1996). Loss of luting composite possibly results in plaque accumulation and, consecutively, marginal staining, postoperative hypersensitivities, recurrent caries or complete loss of the restoration (van Dijken & Hörstedt, 1994). Deep marginal ditching of the luting gap could cause marginal fractures of adhesive inlay systems due to lack of support for the marginal areas of brittle materials, such as enamel or ceramics (Kunzelmann, Deigner & Hickel, 1993).

Evaluation of luting gap wear *in vivo* is difficult to perform. This may be the reason that many authors describe the problem of volume loss within the luting gap but without three-dimensional quantitative analysis of material loss over the time (Isenberg, Essig & Leinfelder, 1992). Heymann reviewed several publications dealing with this problem and found that reported results regarding luting gap abrasion are mainly derived from estimations concerning subjective measuring scales (Heymann & others, 1996).

The difficulty with three-dimensional measuring of luting gap abrasion is represented by complex geometrical conditions of the occlusal surface, overhangs and changes in surface texture of adjacent tooth structure and inlay material over time. These factors considerably complicate the assessment of this particular marginal area. Clinical codes and criteria for evaluation, such as those developed by Ryge, are insufficient for this submacroscopical evaluation (Ryge, 1980; Pelka & others, 1995; Krämer & others, 1999). Therefore, several authors proposed producing replicas and a replica-based estimation of luting composite loss according to comparative scales (Gerbo & others, 1990; Mair, 1990; Lugassy & Moffa, 1985; Pelka & others, 1995). Based on this procedure, selected cases can be evaluated using time-consuming methods for wear analysis of luting composite loss.

Krejci reviewed different methods for quantitative wear evaluation, describing optical, scanning electron microscopic, volumetric and mechanical procedures (Krejci & others, 1993).

For a precise determination of three-dimensional changes within the luting gap, mechanical profilometry (Kreulen & van Amerongen, 1991; Kawai, Isenberg & Leinfelder, 1994; Kunzelmann, 1996) and optical devices (Lang & others, 1994; Lamprecht & others, 1996; Mehl & others, 1997; Roulet & others, 1997) were proposed. Profilometry was selectively used to evaluate representative samples resulting in estimations based on multiple repetitions of line scans (Kawai, Isenberg & Leinfelder, 1994; Noack, 1994; Lamprecht & others, 1996).

Computer technology's rapid development has enhanced computer-based methodologies for wear determination of restorative materials (Krejci & others, 1993; Mehl & others, 1997). Today, optical and mechanical scanning methods are sufficiently operational but only optical procedures are not interfered with by different surface geometries and hardnesses (Pelka, Krämer & Kunzelmann, 1993). Complete tooth surfaces can be optically scanned within an acceptably short period of time, therefore, these systems are valid for clinical mass screenings. However, these optical devices suffer from a relatively minor resolution and practicability (Lang & others, 1994; Kunzelmann, 1996; Lamprecht & others, 1996).

In 1997, Mehl introduced a laser scanner, representing the most accurate optical system for wear evaluation available to date (Mehl & others, 1997). This scanning device's main advantage is active triangulation, thus eliminating moveable parts that could be susceptible to failures. The accuracy of the system is reported at x/y/z=25/2/5µm. Scanning time is 20 ms for each line projection, which is only a few seconds for one investigated restoration. Compare this to mechanical profilometry, which takes several hours for one restoration. A further advantage of the laser scanner is a high depth registration of 20 mm, which is ideal for the optical scanning and measuring of clinically used restorative materials (Mehl & others, 1997). The scanning procedure, without any mechanical contact, even allows the reproduction of deep fissure areas and the assessment of materials exhibiting minimal wear (Pelka, Krämer & Kunzelmann, 1993; Pelka & others, 1993). Furthermore, the accurate depth of its focus enables the evaluation of deep and narrow luting gaps or even gaps resulting from adhesive failures (Mehl & others, 1997).

Nevertheless, computer-based mechanical scanning systems reveal the highest precision. The vertical resolution is reported to be less than 1 µm (Pelka & others, 1993). The significant disadvantage of mechanical scanning is the time required to achieve the data. This study corrected the estimated horizontal accuracy of 1.25 µm from x/y= 10µm x 10µm to x/y = 25µm x25 µm, with a scanning period of one to six hours for each restoration.

Sloping surfaces seldom interfere with this three-dimensional scanning procedure when performing *in vitro* evaluations. However, under clinical conditions, horizontal surfaces are rare situations and steep slopes additionally complicate the scanning procedure compared to laboratory evaluations.

Furthermore, mechanical scanning of adhesive inlays was estimated to be difficult because of the geometrical shape of the scanning needle. By measuring the volume of standardized spherical segments, howe-

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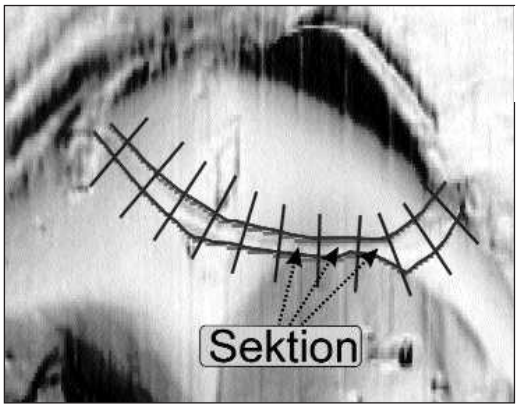

Figure 1A. *The marked luting area (inner points) is widened in 30-50 µm steps (outer points). Bilinear interpolation of both planes computed the marked plane (arrow) being congruent with the upper edge of the real luting gap. The width of the luting area coincidences with the marked width of the plane. The volume below this plane is defined as average depth of the luting gap. The broken line represents the maximum depth of the luting gap. Only areas exhibiting >70% of all marks below the interpolated plane were defined as negative luting gaps.*

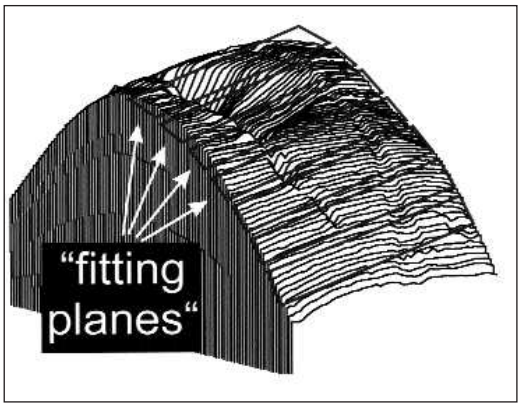

Figure 1B. *Three-dimensional view of a luting area section (programme XPRISM 3D, Khoros): The marked lines correspond with the inner points in Figure 1A.*

ver, mechanical profilometry exhibited an accuracy of 90% (Pelka, Krämer & Kunzelmann, 1993).

Despite these recently developed technologies, no sufficiently valid *in vivo* evaluations regarding luting gap abrasion have yet been published. Therefore, this study aimed to evaluate the substance loss of two differently filled luting composites *in vivo* and assess the influence of time and width of the luting gap.

METHODS AND MATERIALS

Thirty-nine Class II IPS Empress inlays (Ivoclar, Vivadent, FL-9494 Schaan, Liechenstein) (17 premolars, 22 molars, 17 maxillary and 22 mandibular) in 16 patients (13 female, 3 male, with a mean age of 34.7 years) were evaluated at 6, 12, 24, 36, 48 and 72 months. These restorations were part of a larger clinical study (Frankenberger, Petschelt & Kramer, 2000) involving 96 IPS Empress inlays and onlays. Criteria for selection for this study were inlays that exhibited distinct changes of the luting gap area detectable with a probe and cusp inclinations below 45°. Twenty-one of the inlays selected were luted with the mini-filled hybrid restorative resin composite Tetric applied with an ultrasonic insertion technique. The other 18 inlays were placed using a conventional luting composite Variolink Low (both luting agents Vivadent, Schaan, Liechenstein).

The condition of the restorations at each recall was documented by taking impressions (Permagum, ESPE, Seefeld, D-82229 Germany) and fabricating dies (Epoxy Die, Ivoclar).

Three-dimensional scanning of the luting area was implemented with a Profilometer (Perthometer S3P, Perthen, Göttingen, Germany) revealing a resolution of x/y/z = 25/25/0.5 µm. The computer-based analysis of the profilometrically-assessed data was computed using a new software (Xpert for Windows 95, University of Erlangen, D-91054 Germany). The principle of this program is based on a reference plane allowing the three-dimensional data survey of the space below it. This plateau was graphically marked at the margins of the luting gap. Performing the Xpert analysis, average and maximum depths and average and maximum widths were calculated in average steps of 30 to 50 µm (Figure 1). Only areas revealing more than 70% of the measured points below the reference plane computed with Xpert were arbitrarily defined as ditching and consecutively considered for further data analysis.

The occlusal sections of the luting gap were analyzed under a SEM (Leitz ISI 50, Akashi, Tokyo, Japan) at X200 magnification.

The statistical analysis was performed by carrying out non-parametric tests using SPSS/V 8.0 (SPSS Inc, Chicago, IL 60611). Differences between two dependent groups were evaluated by using the Wilcoxon matched-pairs signed-ranks test; differences among several groups were analyzed according to the Kruskal-Wallis test. Independent samples were assessed with the Mann-Whitney U test. The regression analysis was utilized to assess the correlation between width and depth of the luting gap.

To receive a measure independent of the luting gap width, the relative depth of the luting gap was introduced as depth in relation to the complete abraded area:

relative depth = $(\mathbf{l}_{abr} * \mathbf{b}_{abr} * \mathbf{t}_{max.})/(\mathbf{l}_{ges} * \mathbf{b}_{ges})$

$\mathbf{l}_{abr}$: length of worn furrow

$\mathbf{b}_{abr}$: average width of worn furrow

$\mathbf{t}_{max}$: average maximum depths of particular steps evaluated with XPert

$\mathbf{l}_{ges}$: total length of furrow within the occlusal surface

$\mathbf{b}_{ges}$: average width of the furrow

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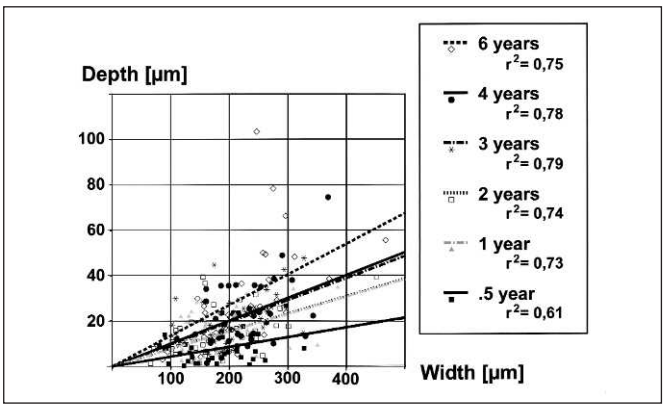

Figure 2. *Correlation of luting gap width and relative depth (RS 1 - 6). Linear regression demonstrates evident correlations.*

Dividing the volume loss of the luting composite between the adjacent surfaces ($\mathbf{l}_{abr}$ * $\mathbf{b}_{abr}$ * $\mathbf{t}_{max}$) by the complete luting area within the occlusal surface (luting gaps * $\mathbf{b}_{ges}$) resulted in the term relative depth representing a measure for luting gap wear.

To limit errors from occurring during the adhesive luting process, such as overextension of luting composite or loss of material due to an oxygen inhibited layer, the six month values were defined as baseline. Subtracting the relative depth of the baseline from the values of the further assessments resulted in the difference Δ **depth**, defined as measure for the substance loss within the luting gap.

RESULTS

The selected restorations exhibited distinct changes within the luting gap even six months after placement. The Xpert analysis revealed ditching as the percentage of the measured margin length of 32% after six months, 48% after 12 months, 46% after 24 months, 55% after 36 months, 59% after 48 months and 65% after 72 months (Table 1). Altogether, the substance loss within the evaluated contact-free area increased significantly over time (Wilcoxon-Test, $p<0.05$). Equally, an increasing relative depth within the first year of the observation period was evident (Table 1).

Table 1: *Substance Loss of the Luting Composites Tested (relative depth), Width, Total length of Luting Gap and Percentage of Negative Sections of the Luting Gap Relating to the Period of Clinical Service.*

Overview of Results						
Recall sessions (RS)	**RS 1**	**RS 2**	**RS 3**	**RS 4**	**RS 5**	**RS 6**
Time (months after placement)	5.9 (1.4)	13.9 (1.9)	25.7 (2.2)	38.6 (1.2)	47.6 (1.4)	70.8 (2.9)
Total length of LS [mm] (SD)	13.8 (6)^{A}	14.5 (7)^{A}	13.7 (6)^{A}	13.8 (6)^{A}	13.8 (6)^{A}	13.8 (6)^{A}
Negative LS related to the total length	32%^{A}	48%^{B}	46%^{B}	55%^{C}	59%^{C}	65%^{C}
Width of LS [µm] (SD)	176 (62)^{A}	182 (67)^{A}	188 (74)^{A}	204 (56)^{B}	226 (52)^{B}	207 (79)^{B}
Relative depth of LS [µm] 26.7 (21)^{C} (SD)	7.4 (6)^{A}	14.3 (9)^{B}	14.6 (10)^{B}	19.8 (11)^{C}	21.9 (14)^{C}	
Relative depth of LS of Variolink Low [µm] (SD)	8.5 (6)^{A}	15.2 (9)^{B}	14.1 (9)^{B}	21.1 (9) C	24.9 (16)^{C}	27.6 (21)^{C}
Relative depth of LS of Tetric [µm] (SD)	6.6 (7)^{A}	13.6 (10)^{B}	15.0 (12)^{B}	18.6 (13)^{B}	19.3 (12)^{C}	26.0 (22)^{C}

Data with same letters are not significantly different (Wilcoxon-test, $p>0.05$).

Table 2: *Correlations Between Luting Gap Width and Wear of Luting Composites*

Recall sessions (RS)	**RS 1**	**RS 2**	**RS 3**	**RS 4**	**RS 5**	**RS 6**
Width of LS [µm] (SD)	176 (62)	182 (67)	188 (74)	204 (56)	226 (52)	207 (79)
Relative depth of LS (SD)	7.4 (6)	14.3 (9)	14.6 (10)	19.8 (11)	21.9 (14)	26.7 (21)[µm]
r Squared	0.61	0.73	0.74	0.79	0.78	0.75
ANOVA (p)	< 0.000	< 0.000	< 0.000	< 0.000	< 0.000	< 0.000
Regression coefficient (SD)	0.04 (.00-8)	0.08 (.008)	0.08 (.007)	0.10 (.008)	0.10 (.009)	0.13 (.012)

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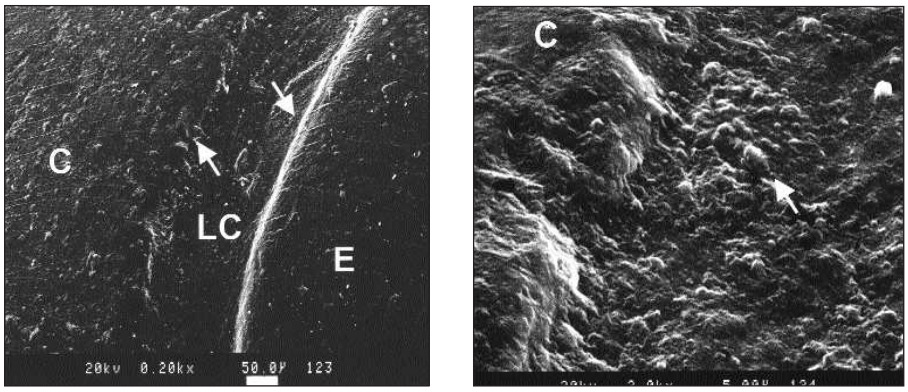

Figure 3. *SEM picture of a typical contact-free area luting gap perfomance characterized by distinct wear of the luting composite (LC) between enamel (E) and ceramic (C)(a:220X, arrow). Adhesive bonding between the interfaces was still intact. 2000X magnification of the same area shows exposed filler particles of Variolink Low (b: arrow).*

A correlation between substance loss and particular location of the inlays was not detectable (mandibulary/maxillary or premolars/molars; Mann-Whitney-U-Test; $p>0.05$). The substance lost was independent of the used luting resin (Mann-Whitney-U-Test; $p>0.05$).

The 234 models revealed a statistically significant linear regression between wear-caused volume loss and width of the luting gap. After the one-year recall, the computed linear regressions remained above $r^2 = 0.7$ (Figure 2, Table 2).

SEM analysis presented different surface characteristics for the occlusal contact and contact-free areas. Focusing on the contact-free areas, the adjacent surfaces (ceramic and enamel) are unchanged. The luting composite showed typical ditching, exhibiting partially exposed filler particles within the composite matrix (Figure 3). The luting composite within the occlusal contact area mainly suffered from surface breakdown with a characteristically rough and cracked surface. The adjacent ceramic and enamel areas also showed wear characteristics, such as micro-cracks. Therefore, it was not useful to assess the occlusal contact wear with the presented methodology due to the possibility of inaccurate results. Adhesive failures between composite and inlay or enamel resulting in gap formations were not detected under the SEM (Figure 3).

DISCUSSION

To date, the methodologies introduced for determining the luting gap wear *in vivo* revealed screening characteristics exclusively. Most of the published results tend to promise higher accuracy as the test system itself, eg, a given accuracy of 1 µm presented in the results, while the used measuring scale is divided in 25 µm steps (Essig & others, 1991; Isenberg, Essig & Leinfelder, 1992; Heymann & others, 1996). These studies reported only few microns of wear beyond the referred accuracy of the scale used in this study (Lugassy & Moffa, 1985). The method reported by O'Neal and others, suggesting cutting replicas into several slices and measuring them under a light microscope at X10 magnification, proved accurate within a range of ± 5 µm (O'Neil, Miracle & Leinfelder, 1993).

Due to its high vertical resolution, mechanical profilometry is described as the most accurate system for detecting surface changes (Krejci & others, 1996; Pelka, Krämer & Kunzelmann, 1993; Frankenberger & others, 1996). This precision is limited by cuspal inclinations of less than 45° and by the inertia of the step motor (Pelka, Krämer & Kunzelmann, 1995). To eliminate the problem arising from slope in the course of this study, only even occlusal reliefs were selected within the pool of 96 restorations. Therefore, twisting phenomena of the scanning needle were reduced to a minimum Pelka, Krämer & Kunzelmann, 1993; Frankenberger & others, 1996).

The geometrical shape of the scanning needle is another critical point potentially influencing the validity of the profilometric data above all for scanning of narrow luting areas. The tip of the diamond needle reveals a radius of 5 µm with an equilateral triangular shape, so that only a furrow depth exhibiting less than 50% of its width is reliably detectable (Noack, 1994; Pelka, Krämer & Kunzelmann, 1993). This data shows widths ranging from 80 to 460 µm and depths of 4 to 104 µm combined, with a clearly evident linear correlation of width and depth (Figure 2). The shrinkage of the die material is estimated to be equal for all models and does not potentially falsify the results.

Lamprecht and others compared mechanical profilometry using the Xpert software with the laser scanner relating to accuracy. Standardized metal furrows with different slopes and diameters served as test substrate controlled by three-dimensional measuring utilizing a light microscope. The investigation demonstrated no statistically significant differences between the two scanning devices (Lamprecht & others, 1996). This finding is also found in an analysis of 13 IPS Empress inlays over three years using 52 models scanned by mechanical profilometry and a laser scanner (Frankenberger & others, 1996; Lamprecht & others, 1996).

During preparation of the data using the Xpert software, the edges between luting area and adjacent structures proved more reliable to mark when profilometry was used (Lamprecht & others, 1996). This

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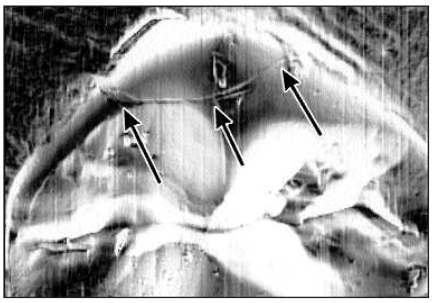

Figure 4A. *Profilomertric scanning of a MOD IPS Empress restoration: a: Grey level picture of the profilometrical record. The edge-enhancement device (Sobel-Operator) marks the borderlines of the luting furrow (marked lines).*

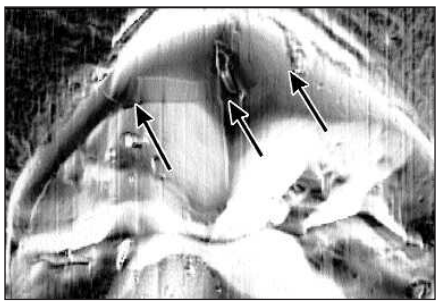

Figure 4B. *Grey level picture of the profilometrical record. A control function filled the luting area shown in Fig. 4a (arrows).*

might be related to the inferior vertical resolution of the laser scanner. Therefore, the percentage of evaluable length of the luting gap was significantly smaller than that registered by use of mechanical profilometry (Lamprecht & others, 1996).

The central problem with using the Xpert software is marking the edges for the reproduction of the reference plane. Inaccurate plotting may result in inadequate reproduction of real anatomic structures or wear phenomena. Therefore, an additional visual control, provided by the software Xprism 3D (Lamprecht & others, 1996), is required. Using this control function for rebuilding abraded areas within the luting gap completes the Xpert analysis and provides a reproducible and reliable methodology for determination of luting gap wear. Meticulous selection of restorations revealing slopes <45° with detectable ditching enables an accuracy of profilometric data of ±2 µm (Figure 4) (Pelka, Krämer & Kunzelmann, 1993).

This study evaluated the influence of different luting composites and variables, such as the width of the luting gap, location of the restored tooth and contact area on luting gap abrasion.

Only changes between the adjacent structures (enamel and IPS Empress ceramic) were assessed because both materials show an equal clinical wear behavior, so they were taken as reference for abrasion (Kunzelmann, 1996). The rough data produced by XPert required several mathematical transactions because the influence of the exposed and worn luting area increased the resulting standard deviations. Therefore, dividing the volume loss by abraded area resulted in the measure-relative depth.

In contrast to wear analyses of direct posterior resin composite restorations, the wear data of this study showed no statistically significant influence of the location of the restoration within the oral environment. This is due to the exclusively evaluated wear within the contact-free area. Therefore, the different occlusal forces occuring in particular areas did not show a significant impact for the results of this study.

The correlation between depth and width of the luting gap was clearly evident in the course of this observation (Figure 2). These results confirm *in vitro* evaluations by use of the ACTA wear simulator (DeGee, ten Harkel-Hagenaar & Davidson, 1985), indicating significantly more volume loss when larger widths of the ditching area are apparent (Noack, 1994). This effect was only observed within the contact-free area.

Compared with other studies evaluating the wear of luting composites (Isenberg, Essig & Leinfelder, 1992), this data indicated the most intensive abrasion within the first year of clinical service.

The influence of antagonistic contact phenomena was not sufficiently assessed until now. Nevertheless, the influence of food abrasion (relative depth within contact- free area: 27 µm after six years) on the results of the study is evident. The introduction of the ultrasonic insertion technique was combined with hopes of increased abrasion resistance due to the higher filler content of the composites used with this methodology (Noack, Roulet & Bergmann, 1991; Frankenberger & others, 1996; Krämer & others, 1999). Prior to this study, estimates of the amount of loss of luting resin had been made (Essig & others, 1991; O'Neal, Miracle & Leinfelder, 1993). Roulet reported a worst-case investigation of 42 Dicor (DeTrey Dentsply, Konstanz, D-78467 Germany) inlays with clinically-detectable high-volume loss inside the luting gap (Roulet & others, 1997). The micro-filled luting composite Microfil Pontic C (Kulzer, D-41540 Dormagen, Germany) revealed significantly more luting gap wear than the fine particle hybrid composites Duo Cement (Coltène, Altstätten, CH9450 Switzerland), Sono Cem (ESPE, Seefeld, Germany), and the inhomogeneously micro-filled composite Dual Cement (Vivadent). However, important data are missing from that evaluation because no baseline data were assessed, and the recall period varied between 14 and 107 months (Roulet & others, 1997).

In contrast, the present profilometric study quantitatively analyzed luting gap abrasion using the Xpert software. A correlation between filler content of luting composites and wear resistance was not evident. Although there was a significant difference after four years, after six years of clincial service the higher filled

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restorative composite Tetric (Vivadent) exhibited a similar wear behavior as the low-viscosity material Variolink Low (Vivadent), respectively ($p>0.05$; Table 1).

The ditching formation with adhesive inlays is an incontrovertible fact in adhesive dentistry, but this study demonstrated that clinical consequences of the luting resin wear do not threaten the survival of such restorations (Krämer & others, 1999). Problems arising from technique-sensitive placement and conditioning procedures with consecutive formation of marginal gaps still remain the significantly crucial causalities for marginal failures of adhesive inlays.

CONCLUSIONS

The results of this study demonstrate that mechanical profilometry is suitable for three-dimensional scanning of luting gaps.

The Xpert software proved to be a useful tool for the evaluation of luting gap wear.

The evaluated mini-filled hybrid resin composite showed similar wear characteristics to the conventional low-viscosity luting composite.

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Eight-Year Clinical Evaluation of Fired Ceramic Inlays

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Clinical Relevance

The *in vivo* longevity of fired ceramic inlay restorations dropped from 92% to 80% between the sixth and eighth year after restoration because bulk fracture occurred in five cases (11%) during these two years.

SUMMARY

This study evaluated the quality of fired ceramic inlay restorations consisting of a feldspathic porcelain system (G-Cera Cosmotech II, GC Co, Tokyo, Japan) after eight years in vivo**.**

Forty-five fired ceramic inlays (for 26 premolars and 19 molars; Class I in 12 teeth, Class II in 31 teeth and onlay in two teeth) were placed in 25 patients. All restorations were evaluated at the time of placement and at 6 months, 1, 2, 4, 6 and 8 years after placement using modified USPHS criteria. Replicas of the restorations were observed with a scanning electron microscope (SEM) to evaluate the degradation of the marginal area and wear loss of the restoration.

Longevity was observed in 80% of the fired ceramic inlay restorations at eight years (Kaplan-Meier method), although it was 92% at the six-year observation. Marginal fracture was detected in 11 restorations (22%), including bulk fracture in five (11%), which had first occurred during the last two years. Recurrent caries was observed in three (7%) cases and marginal discoloration in 14 (31%).

SEM evaluation disclosed marginal microfractures in 77% of the restorations, wear in 36% and wear of the resin cement along the margin in 74% at eight years. No significant difference was observed in each of these three characteristics between molars and premolars.

This longitudinal eight-year clinical observation suggested that fired ceramic inlay restorations made by the G-Cera Cosmotech II system are clinically acceptable. However, critical failure as bulk fracture may become a future problem since marginal disintegration was detected in 77% of the restorations from microscopic and macroscopic perspectives.

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INTRODUCTION

Ceramic inlay restorations have become popular for conservative posterior restorations and present an aesthetic appearance with less reduction of the restored tooth than that required for a crown. We previously reported a six-year clinical evaluation of fired ceramic inlays in 49 molars and premolars (Hayashi & others, 1998). There have been only a few long-term clinical studies of the longevity of ceramic inlay restorations (van Dijken, Höglund-Aberg & Olofsson, 1998; Roulet, 1995; Noack & Roulet, 1994), although some short-term clinical studies have been conducted (Friedl & others, 1996; Höglund & others, 1994; Stenberg & Matsson, 1993; Krejci, Krejci & Lutz, 1992; Sjogren & others, 1992; Bessing & Molin, 1990).

From our previous study, longevity was observed in 92% of the fired ceramic inlay restorations after six years (Kaplan-Meier method). However, marginal fracture was detected in seven cases (15%) and marginal discoloration in 11 cases (23%). Favorable results were obtained in terms of color match and no bulk fracture, tooth fracture or missing restoration was detected.

A scanning electron microscope (SEM) evaluation disclosed marginal micro-fractures in 55% of the restorations, wear in 19% and wear of resin cement along the margin in 41% at six years.

The longitudinal six-year clinical observation suggested that fired ceramic inlay restorations are aesthetic, durable and clinically acceptable. However, in some cases disintegration of the restoration, such as marginal fractures, marginal discoloration or wear of the restorative material was detected. Therefore, further follow-up is needed for restorations showing degradation of quality.

This *in vivo* study evaluated the quality of fired ceramic inlay restorations over eight years. In particular, the prognoses of the restorations in which disintegration as marginal fracture or marginal discoloration were detected at six years were carefully observed. Moreover, the marginal quality was evaluated by SEM and the mechanism of disintegration for fractured cases was analyzed.

METHODS AND MATERIALS

Clinical Procedures

The clinical procedures were described in detail previously (Hayashi & others, 1998).

A total of 45 fired ceramic inlays were placed in 25 patients using a feldspathic porcelain system (G-Cera Cosmotech II, GC Co, Tokyo, Japan) at the Department of Conservative Dentistry of Osaka University Dental Hospital between October, 1990 and March, 1991. Of the 45 teeth treated, 26 were premolars and 19 were molars (Table 1). The type of restoration was Class I inlay in 12 teeth, Class II inlay in 31 teeth and onlay in two teeth.

Table 1: *Distribution of Restored Teeth*

Location		Cavity Form	Number of Restored Teeth
Upper	Premolar	Class I	0
		Class II	12
		Onlay	0
	Molar	Class I	1
		Class II	0
		Onlay	0
Lower	Premolar	Class I	1
		Class II	12
		Onlay	1
	Molar	Class I	10
		Class II	7
		Onlay	1
Total			45

Direct and Indirect Evaluation

Direct and indirect evaluations were performed as described previously (Hayashi & others, 1998) at the time of placement, and at 6 months, 1, 2, 4, 6 and 8 years.

For direct evaluation, the 15 characteristics shown in Table 2 were evaluated according to the rating criteria indicated. For indirect evaluation, a replica was observed under a scanning electron microscope (S-2100B, Hitachi Ltd, Tokyo, Japan) and marginal micro-fracture, wear of the restoration and wear of resin cement were evaluated.

Statistical Analysis

The Kaplan-Meier method, the Spearman's rank correlation test and the Mann-Whitney test were employed for statistical analysis as described previously (Hayashi & others, 1998).

RESULTS

Direct Evaluation

For six restorations, replacement was performed because recurrent caries was detected at 27 months, spontaneous pain occurred at 49 months and bulk fracture occurred at 90, 96, 99 or 100 months. Recurrent caries, which was repairable, was detected in one additional case at the six-year evaluation. Bulk fracture, which was repairable, occurred in two more cases at 86 and 90 months. Therefore, longevity was observed in 80% of the fired ceramic inlay restorations at eight years (Kaplan-Meier method) as shown in Figure 1.

There was no macroscopically-visible wear of the restorative material or opposing teeth, tooth fracture, missing restorative material or change of the proximal contact relationships.

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Table 2: *Criteria for the Clinical Evaluation of Porcelain Inlays*

Characteristic	Rating	Criteria
Color match	Alpha	No mismatch in color, shade and translucency between restoration and adjacent tooth structure
	Bravo	Mismatch between restoration and tooth structure within the normal range of color, shade and translucency
	Charlie	Mismatch between restoration and tooth structure outside the normal range of tooth color, shade and translucency
Surface texture	Alpha	Surface of restoration is smooth. No irritation of adjacent tissue
	Bravo	Surface of restoration is slightly rough, can be refinished
	Charlie	Surface deeply pitted with irregular grooves, cannot be refinished
Marginal adaptation	Alpha	No visible evidence of ditching along the margin
	Bravo	Visible evidence of ditching along the margin not extending to the DE junction
	Charlie	Dentin or base is exposed along the margin
	Delta	Restoration is mobile, fractured or missing
Marginal discoloration	Alpha	No discoloration on the margin between the restoration and tooth structure
	Bravo	Discoloration on the margin between the restoration and tooth structure
	Charlie	Discoloration has penetrated along the margin of the restorative material in a pulpal direction
Wear	Alpha	No change of form or surface condition of restorative material
	Bravo	Partial change of form or surface condition of restorative materia
	Charlie	Total change of form or surface condition of restorative material
Wear of antagonistics	Alpha	No change of form or surface condition of antagonistics
	Bravo	Partial change of form or surface condition of antagonistics
	Charlie	Total change of form or surface condition of antagonistics
Proximal contact relationships	Alpha	Proper contact, dental floss goes through only under pressure
	Bravo	Weak contact, dental floss goes through with no pressure
	Charlie	No evidence of approximal contact

Marginal fracture, bulk fracture, tooth fracture, missing restoration, recurrent caries, spontaneous pain, sensitivity to varying temperatures, and sensitivity to occlusal loading were also evaluated as present or absent.

The color of all restorations was clinically acceptable at the time of placement. The color matching remained unchanged throughout the observation period.

The rating of marginal adaptation for some restorations decreased with time as shown in Table 3, and five restorations showed grade Bravo, one grade Charlie and five grade Delta at eight years. Finally, fracture was found in 11 restorations (24%) after eight years. Five grade Bravo restorations had macroscopic marginal fractures, all located in the occlusal portion. One grade Charlie restoration fractured to the dentin in the occlusal portion. The fractured inlays graded Bravo or Charlie were adjusted by polishing or were repaired with resin composite because only minor parts of the marginal ridges had fractured. Three grade Delta restorations, which showed bulk fractures, required replacement. One MOD inlay in a lower second premolar fractured at the center of the isthmus at 90 months. Another MO inlay in a lower first molar fractured at the connecting area between the occlusal and proximal portions at 96 months. One OB Class I inlay in a lower first molar fractured at the buccal proximal area at 90 months. One MO inlay in an upper second premolar and an OD inlay in an upper first premolar fractured at the occlusal isthmus at 99 and 100 months, respectively. The MOD, MO and OD inlays needed replacement and the OB inlay was repaired with resin composite because the fractured area was limited.

Marginal discoloration was detected in 14 restorations (31%) at the end of eight years. This number increased markedly during the fourth through eighth years as shown in Table 4.

Among the 15 categories of direct evaluation, marginal adaptation and marginal discoloration showed significant declines in quality with time (Spearman's rank correlation test, $p<0.01$).

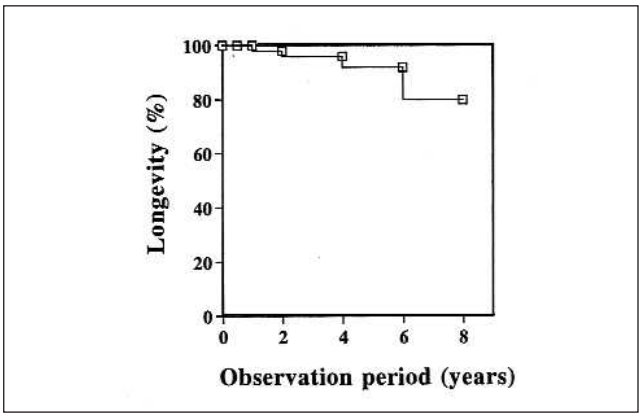

Figure 1. *Longevity of fired ceramic inlays over eight years.*

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Table 3: *Results of Clinical Evaluation of Marginal Adptation*

Period	Alpha	Bravo	Charlie	Delta
Placement	44	1	0	0
6 months	43	2	0	0
1 Y	42	3	0	0
2 Y	40	5	0	0
4 Y	38	6	0	0
6 Y	37	6	0	0
8 Y	32	5	1	5

Table 4: *Results of Clinical Evaluation of Marginal Discoloration*

Period	Alpha	Bravo	Charlie
Placement	45	0	0
6 months	45	0	0
1 Y	44	1	0
2 Y	44	1	0
4 Y	41	3	0
6 Y	32	11	0
8 Y	27	14	0

Table 5: *Results of Clinical Evaluation of Postoperative Sensitivity*

	Sensitivity			
	Temperature		Occlusal Loading	
Period of Time	+	-	+	-
Before Treatment	6	39	0	45
Placement	4	41	5	40
6 months	1	44	1	44
1 Y	0	45	0	45
2 Y	1	44	0	45
4 Y	0	44	0	44
6 Y	0	43	0	43
8 Y	5	38	4	39

Evidence of sensitivity to temperature: present, +; absent, -.
Evidence of sensitivity to occlusal loading: present, +; absent, -.

Table 6: *Findings of SEM Observation*

Category	Marginal Fracture		Wear of Restoration		Wear of Resin Cement	
Period	+	-	+	-	+	-
Placement	1	44	0	45	0	45
6 months	7	38	2	43	1	44
1 Y	9	36	5	40	5	40
2 Y	14	31	7	38	9	36
4 Y	20	24	10	34	15	29
6 Y	23	20	11	32	17	26
8 Y	30	9	14	25	29	10.

Marginal Fracture: Marginal micro-fracture involving crack or chipping of ceramics or enamel.
Wear of Restoration: Change of form or surface texture of the restoration.
Wear of Resin Cement: Wear loss of the resin composite cement.

Recurrent caries was detected in an OD inlay, which fractured at 99 months. The caries was adjacent to the pulp and, therefore, indirect pulp capping was performed with an adhesive resin composite.

Postoperative sensitivity is shown in Table 5. Three Class II restorations with bulk fracture presented sensitivity to temperature and occlusal loading at eight years and all were replaced. The OB Class I restoration with bulk fracture presented sensitivity to temperature only.

SEM Evaluation

Replicas of 39 restorations were observed by SEM. The three restorations needing replacement, and another three from which replicas could not be prepared because of technical errors, were excluded. The results are summarized in Table 6.

Marginal micro-fracture was detected in 30 restorations (77%) at eight years, including 11 macroscopically visible marginal fractures.

Wear of the restorative material, accompanied by wear of the opposing teeth, was noted in 14 restorations (36%) at eight years. In 11 of the 14 cases, wear was observed where the surface irregularities of the porcelain caused by occlusal adjustment had not been adequately polished. In another three cases, very superficial porcelain disintegration due to continuous occlusal loading was seen during the sixth-to-eighth years.

Wear of resin cement was detected in 29 restorations (74%) at eight years. It markedly increased from six-to-eight years accompanied by marginal micro-fractures.

All three of the characteristics in the SEM evaluation showed significant degradation with time (Spearman's rank correlation test, $p<0.01$).

There was no difference between the molars and premolars for any incidences of the three characteristics in the SEM evaluation (Mann-Whitney test, $p>0.05$).

Figure 2 shows crack propagation on a Class II ceramic inlay in a left upper premolar. The cracks extended from both the buccal and palatal margins at the occlusal area and almost connected together. This restoration resulted in bulk fracture and required replacement at 100 months. This crack propagation view was taken two months before the bulk fracture. Marginal fracture was observed at both the buccal and palatal margins, from which the cracks propagated.

Figure 3 shows longitudinal disintegration on the occlusal margin accompanied by wear of the resin

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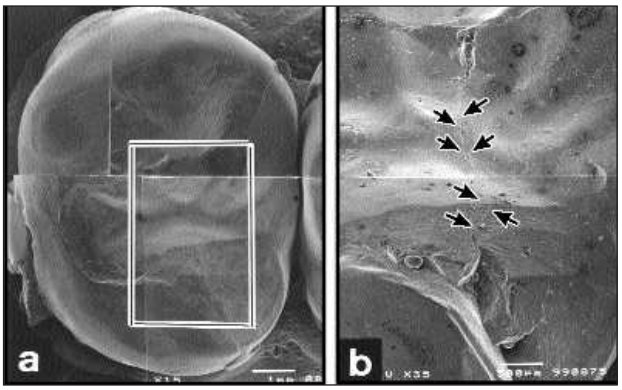

Figure 2. *Crack propagation on a Class II (OD) ceramic inlay in a left upper first premolar. a: An overview of restored tooth just after placement. b: An enlargement of box area in Figure 2a. Crack propagation through buccal and palatal margin at eight years after placement.*

cement and micro-fracture of ceramics. The restored tooth is the same one shown in Figure 2.

The smooth margin was observed at one month after placement (Figure 3a). Micro-fracture of ceramics had started one year after placement with surface irregularity of ceramics, and small cracks were found on the fractured surface of ceramics (Figure 3b). At two years after placement, additional cracks propagated at right angles to the initial cracks (Figure 3c). At four years after placement, the irregularity of the ceramic surface became severe and the cracks connected from all directions (Figure 3d). The ceramics surrounded by the cracks seemed to collapse easily. The micro-fractured areas became macroscopically visible and cracks, which were the cause of bulk fracture, extended on the occlusal surface at eight years after placement (Figure 3e).

Figure 4 shows marginal disintegration of both ceramics and enamel. A smooth surface was observed on the marginal enamel at one month after placement, although small irregularities were detected on the marginal ceramics (Figures 4a and 4b). At eight years after placement, the irregularity of ceramics was advanced and the disintegrated area had expanded (Figures 4c and 4d). At the same time, the marginal enamel had collapsed in the area adjacent to the ceramics.

Figure 5 shows the different types of disintegration on the margin. At one month after placement, resin composite cement covered the entire buccal margin and a smooth ceramic surface was observed except for the approximal area (Figures 5a and 5b). However, the resin cement wore completely along the margin at eight years after placement (Figures 5c and 5d). Marginal ceramics fractured at the center of occlusal area in the same pattern as shown in Figures 3 and 4. The important finding was that the ceramics, indicated with arrows in Figure 5d, disintegrated at an internal area away from the marginal edge, not along the margin. The disintegrated ceramics fractured with a mosaic pattern.

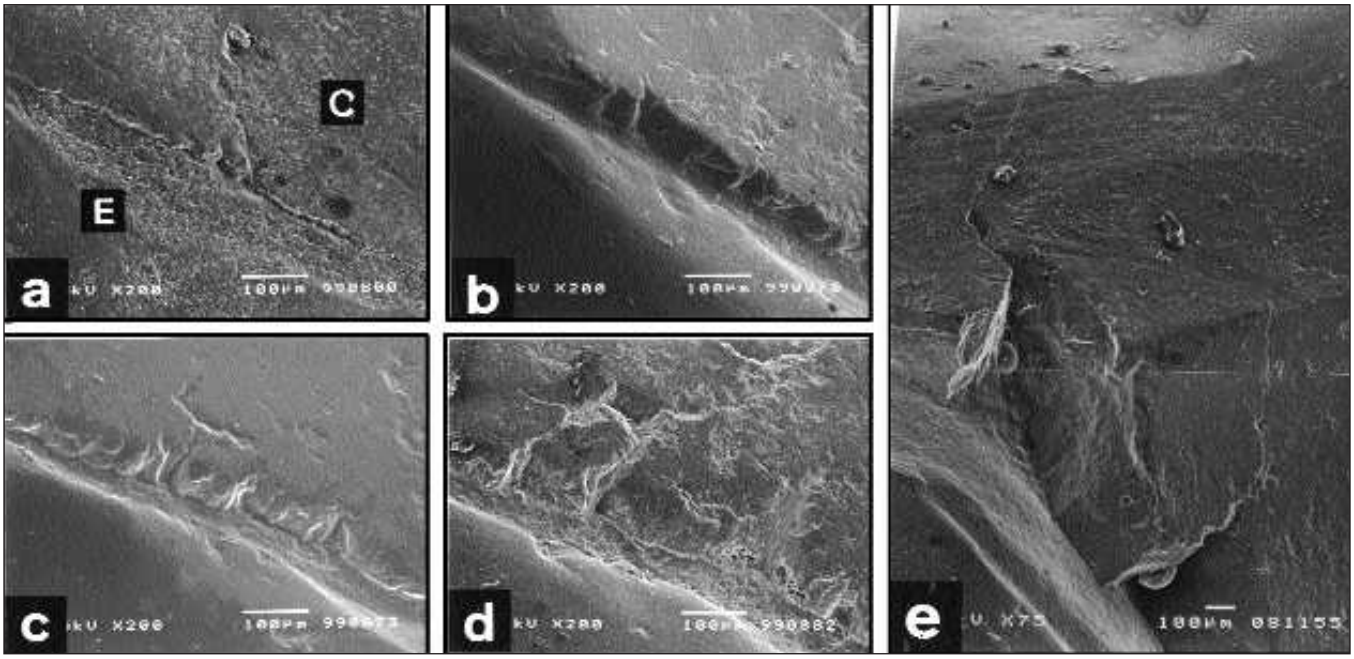

Figure 3. *Longitudinal disintegration of palatal-occlusal margin on a Class II (OD) ceramic inlay in a left upper first premolar. a: Smooth margin was observed at one month after placement. b: Marginal micro-fracture was detected at one year after placement. c: The fractured area was expanded at two years after placement. d: Crack initiation was observed in the expanding fractured area at four years after placement. e: The micro-fracture proceeded to macroscopic fracture and crack propagation was found at eight years after placement.*

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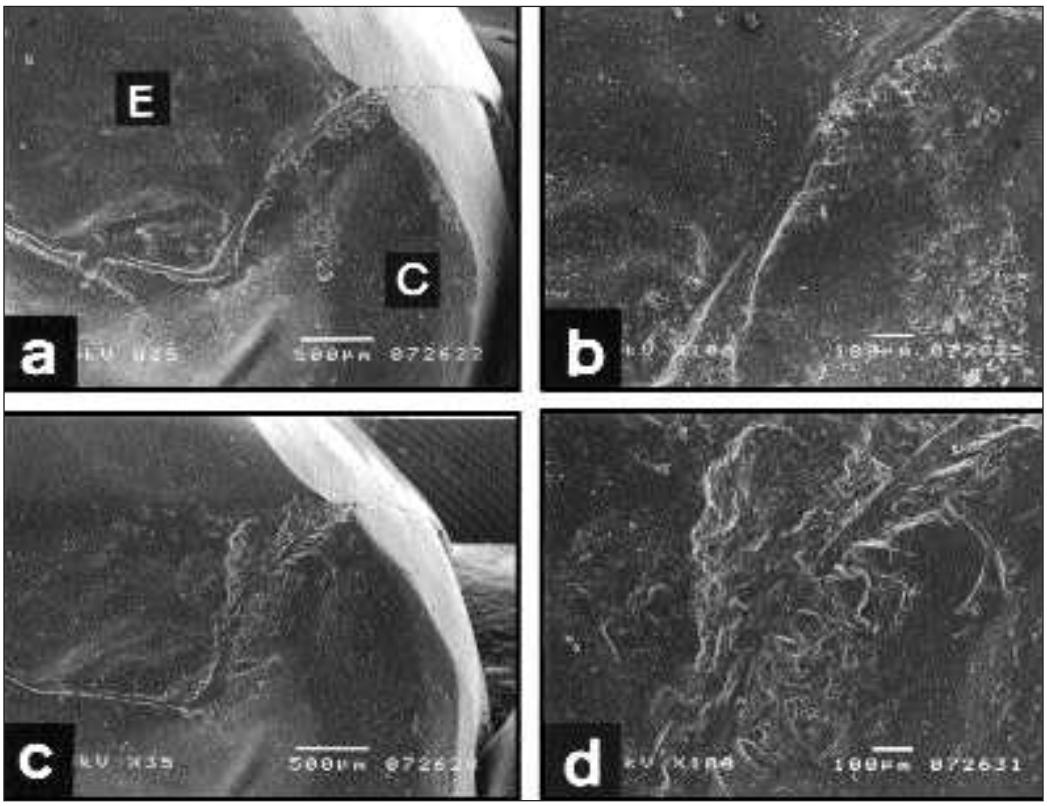

Figure 4. *Marginal micro-fracture on a Class II (OD) ceramic inlay in a left lower first premolar. E: enamel, C: ceramics. a: An overview of disto-buccal margin at one month after placement. b: Enlarged photograph of Figure 4a. the disto-buccal margin at x100 magnification. c: An overview of disintegrated area at eight years after placement. d: Enlarged photograph of Figure 4c. The fractured area at x100 magnification.*

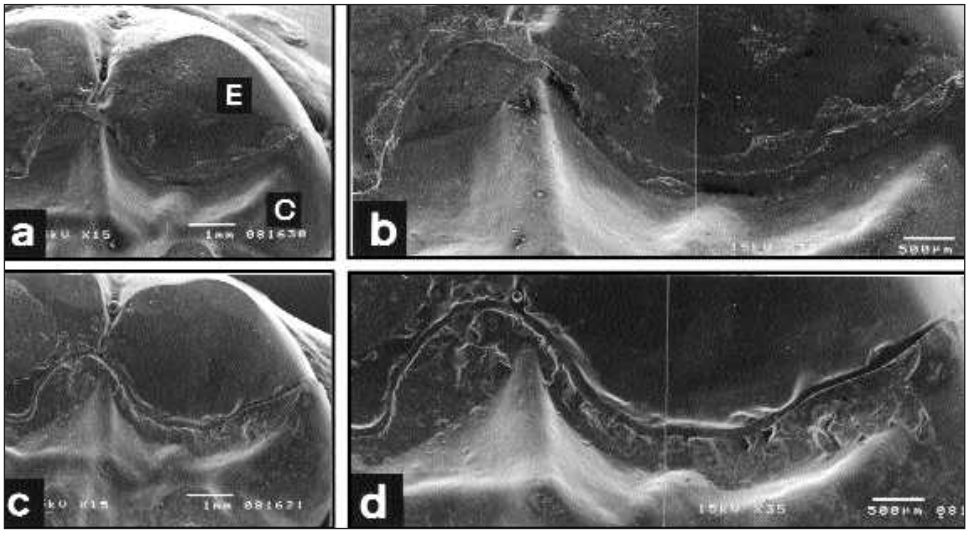

Figure 5. *Marginal disintegration causing wear of the resin composite cement and micro-fracture of ceramics on a Class II (OD) ceramic inlay in a left lower first molar. E: enamel, C: ceramics, a: An overview of buccal margin at one month after placement. b: Enlarged photograph of Figure 5a .The buccal margin at x35 magnification. c: An overview of marginal disintegrated area at eight years after placement. d: Enlarged photograph of Figure 5c. The disintegrated area is indicated by arrows at x35 magnification.*

Figure 6 shows longitudinal wear of the resin cement, and the marginal gap is revealed clearly as wear of the resin cement with time. However, marked collapse of enamel and ceramics was not detected.

DISCUSSION

This study focused on the categories in which marked changes were observed from the sixth to eighth years because the status of the fired ceramic inlay restoration up to six years after placement was reported previously (Hayashi & others, 1998).

Longevity

We previously reported that the longevity of fired ceramic inlay restorations was 92% at six years (Hayashi & others, 1998). Only a few studies have reported long-term clinical evaluations over six years for ceramic inlay restorations. The reported failure rate for Dicor inlay restorations is 24% at six years (Roulet, 1995). For fired ceramic inlays, van Dijken and others (1998) reported a six-year failure rate of 26% when luted with glass ionomer cement, but of 12% when luted with dual-cured resin composite.

In the six-year evaluation, the longevity of the fired ceramic inlay restorations was at least comparable, and in some cases, better than that reported for other ceramic inlay restorations. However, the longevity dropped from 92% to 80% between the sixth and eighth years after restoration (Figure 1)

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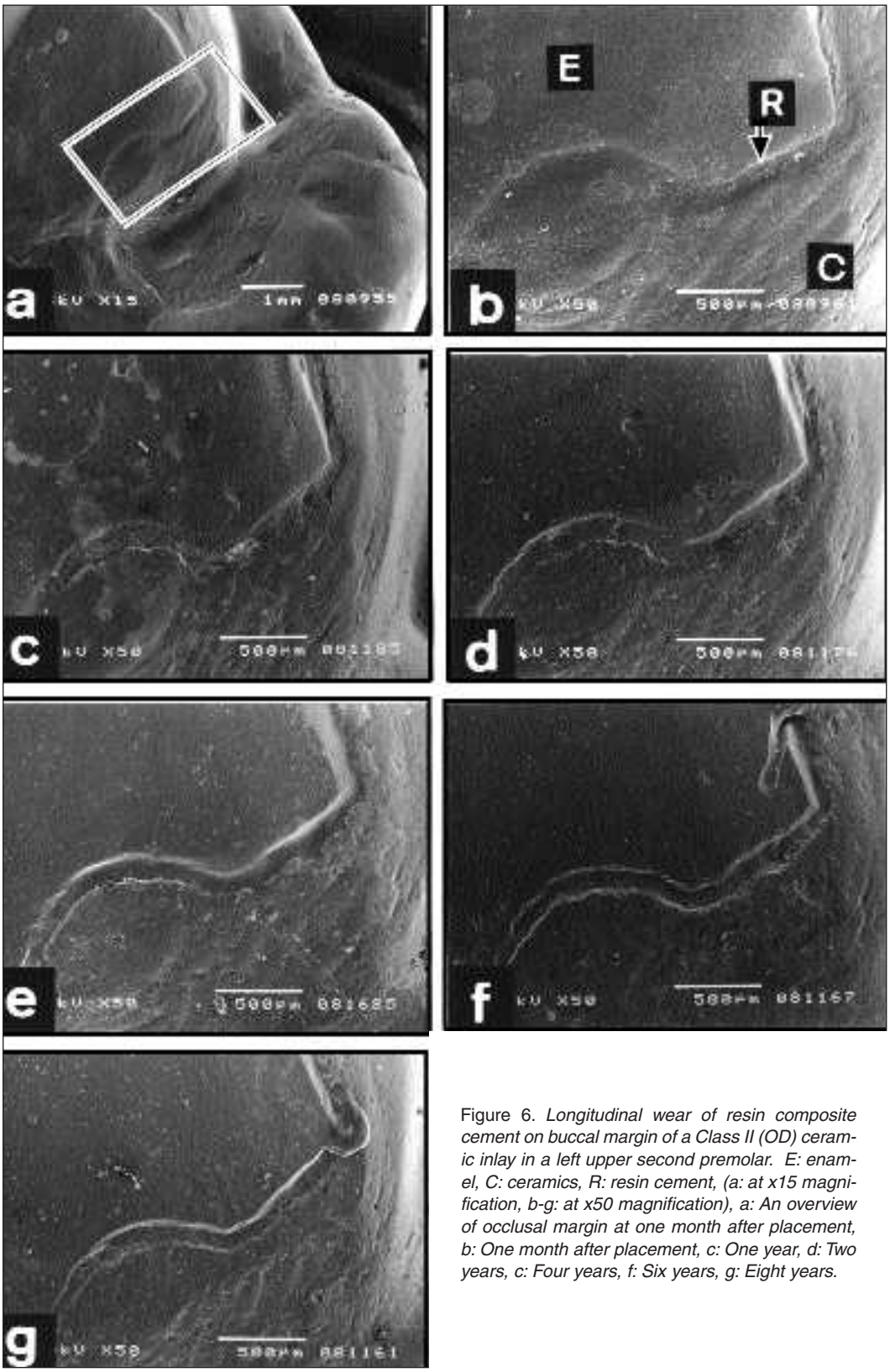

Figure 6. *Longitudinal wear of resin composite cement on buccal margin of a Class II (OD) ceramic inlay in a left upper second premolar. E: enamel, C: ceramics, R: resin cement, (a: at x15 magnification, b-g: at x50 magnification), a: An overview of occlusal margin at one month after placement, b: One month after placement, c: One year, d: Two years, c: Four years, f: Six years, g: Eight years.*

because additional failures due to bulk fracture occurred for the first time during the last two years.

The longevity might drop further beyond eight years because crack initiation in the ceramics, which will propagate to a bulk fracture, might have already started on the internal surface despite being invisible from the external surface (Peters, DeVree & Brekelmans, 1993).

Moreover, the adhesion ability of resin composite cement becomes weak due to continuous mastication force delivered to the margin. When the effect of reinforcement by adhesion is lost, marginal ceramics on the margin is likely to fracture microscopically. Such microdisintegration will expand and lead to initiation of a critical fracture. Therefore, continuous follow-up is indispensable.

Marginal Adaptation

Although grade Alpha marginal adaptation was seen in 98% of the inlays at placement, the percentage of good adaptation dropped to 87% at six years and 76% at eight years (Table 3) due to macroscopic marginal and bulk fracture.

Limited information has been presented regarding long-term results. Roulet (1995) detected marginal disintegration in 14% of Dicor inlay restorations at six years. van Dijken & others (1998) reported that unacceptable marginal adaptability was observed in 26.7% of cases luted with glass-ionomer

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cement, but in 10.6% of those luted with dual-cured resin composite. It is difficult to compare our rate of marginal integrity with that of other long-term studies because no other studies extend beyond six years after placement.

Note that bulk fracture was detected in four cases for the first time during this eight-year clinical evaluation. Two cases presented marginal fracture one year after restoration at the thinned area, and the marginal fractures converted to bulk fractures with additional crack propagation. In the other three cases, it occurred without any precursor.

Cause of bulk fracture was deduced as follows: crack initiation begins beneath the surface of the ceramics and the crack propagation progresses with masticatory forces as indicated by Peters (1993). Eventually, visible fractures will appear when the cracks connect completely through the inlay. If the adhesion between the restored tooth and ceramics fails, crack initiation and propagation will occur easily and progress rapidly.

In one case, failure of adhesion was suspected as the cause of fracture because the margin of the proximal area was located at the subgingival level where the conditions for the adhesion are considered severe. In another case decline of adhesion was also suspected as a cause of fracture because conventional glass-ionomer cement, used as the lining and base material and does not have a strong adhesive force to resin-composite cement, was exposed extensively on the fractured surface. Based on these cases, we can conclude that the adhesive ability of the resin composite cement has strong effect on the durability of the ceramic inlay restoration. Care should be taken to ensure suitable conditions for adhesion.

In the other two cases, the thickness at the fractured area was insufficient to withstand the masticatory force.

Continuous follow-up is indispensable because invisible cracks will appear on the external surface beyond the eight-year observation of this study.

Marginal Discoloration

Marginal discoloration was found in 14 (31%) of restorations, and the number of discolored restorations increased markedly at the fourth year. The pigmentation molecules are apt to stay and adsorb at disintegrated margins caused by micro-fracture or wear of resin cement. These disintegrated areas remain and will expand with time, as stated above. Therefore, discoloration will continue to increase with marginal disintegration beyond this study's observation period.

The brown discoloration on the margin of the inlay could not be removed by polishing, and the marginal discoloration of the resin cement was permanent. Therefore, in terms of marginal discoloration, the aesthetics of the fired ceramic inlay restorations could not be described as stable. Nevertheless, the ceramics themselves remained aesthetic throughout the observation period.

Findings from SEM Observation

Marginal micro-fracture was detected by SEM observation in 77% of the restorations at the eighth year. The fractured area was found to have expanded, and there was no tendency for marginal micro-fractures to decline with time.

Figure 2 shows crack propagation and Figure 3 shows the process of typical marginal disintegration, which developed to bulk fracture in the same Class II (OD) restoration in a right upper first premolar. Figures 2-b and 3-e are SEM photographs taken two months before the bulk fracture.

First, a gap due to micro-fracture of the ceramics was observed at one year after placement, and the marginal ceramics collapsed with time as the micro-cracks propagated. Then the micro-fracture expanded in area and became macroscopically visible. Finally, the critical crack that caused bulk fracture started from the macroscopically fractured area. From this case, the process of fracture *in vivo* could be traced longitudinally, and the mechanism of fracture was clearly revealed. It can be concluded that micro-fracture could be a cause of bulk fracture because the initial crack, which started from the micro-fracture, will propagate and develop through the inlay.

To prevent the micro-fracture of ceramics, the adhesive ability of luting cement should be improved as well as reinforcement of the ceramics, themselves, because it would contribute to reinforcement of the margin.

It is worth noting that the bulk fractures observed in three of the Class II inlays in this study occurred in the same areas as calculated by a computer in a 3-D trial study (Peters & others, 1993). The results of this study corroborate the validity of the previous computer study.

In 16 cases, irregularity and disintegration of marginal enamel was observed to correspond with disintegration of marginal ceramics as shown in Figure 4. This disintegration of the enamel progressed with peeling of layered particles from the surface. Free enamel, which is apt to collapse, tends to remain at the non-beveled cavosurface margin. Careful attention should be paid to designing the occlusal margin so as to avoid direct contact with opposing teeth.

Figure 5 shows different disintegration of marginal areas. Marginal ceramics fractured microscopically accompanied by micro-cracks on the center of the occlusal margin, with the same pattern as in Figure 3. Ceramics on the disto-occlusal area cracked in a mosaic pattern at approximately 20 μm internal from the mar-

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ginal edge, while the very marginal ceramics remained smooth at eight years after placement. This fractured area was on the functional cusp side, and repeated occlusal force must have caused the cracks. Marginal fracture of the ceramics occurred on the functional cusp side in 66% of the fractured cases.

On the other hand, although wear of resin cement, which is the precursor of micro-fracture of ceramics, was revealed on the bucco-occlusal margin (Figure 6), marked fracture of ceramics was not detected. This is due to the margin being on the non-functional side and, therefore, less occlusal force was loaded compared with the functional side.

It can be concluded that the occlusal force has an important effect on the disintegration of ceramic restorations. Marginal design should be decided carefully and precisely to avoid excessive direct loading on the margin, as this has a critical effect on the longevity of the ceramic restoration.

From the eight-year observation, wear of superficial ceramics occurred in the areas at which occlusal force was continuously loaded. In these areas, the surface irregularities appeared as a complex and sequential process of micro-collapse and micro-wear. This disintegration of the surface may last and become severe, thereafter, because occlusal loading will attack the same area continuously. If crack initiation starts from this type of disintegration, wear of ceramics could become a macroscopic fracture.

Wear of the resin cement was first caused by masticator action on the margin and the thinned porcelain without the support of the resin cement gradually developed a marginal micro-fracture, especially on the functional side. Eventually, the disintegrated area became macroscopic, and crack initiation and propagation developed from this marginal micro-disintegration. Therefore, the physical properties of resin composite cement need to be improved in terms of wear resistance because the initial phenomena of disintegration is wear of the resin composite cement.

CONCLUSIONS

Favorable conditions remained in 80% of fired ceramic inlay restorations up to eight years after placement. This restoration technique, therefore, seems clinically acceptable as an aesthetic and conservative treatment method for molar and premolar restoration. However, critical failure as bulk fracture was first observed and the marginal disintegration was growing worse microscopically with time. Further follow-up is indispensable for restorations where disintegration is observed.

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Laboratory Research

Brushing Abrasion of Luting Cements Under Neutral and Acidic Conditions

W Buchalla • T Attin • E Hellwig

Clinical Relevance

A material with low-brushing abrasion should be used for cementing a restoration with an inevitable marginal gap. The brushing abrasion resistance of the luting material in an acidic environment should be considered if the patient shows patterns of erosive tooth wear or tends to accumulate plaque.

SUMMARY

Four resin based materials (Compolute Aplicap, ESPE; Variolink Ultra, Vivadent; C&B Metabond, Parkell and Panavia 21, Kuraray), two carboxylate cements (Poly-F Plus, Dentsply DeTrey and Durelon Maxicap, ESPE), two glass-ionomer cements (Fuji I, GC and Ketac-Cem Aplicap, ESPE), one resin-modified glass ionomer cement (Vitremer, 3M), one polyacid-modified resin composite (Dyract Cem, Dentsply DeTrey) and one zinc phosphate cement (Harvard, Richter & Hoffmann) were investigated according to their brushing resistance after storage in neutral and acidic buffer solutions. For this purpose 24 cylindrical acrylic molds were each filled with the materials. After hardening, the samples were stored for seven days in 100% relative humidity and at 37°C. Subsequently, they were ground flat and polished. Then each specimen was covered with an adhesive tape leaving a 4 mm wide window on the cement surface. Twelve samples of each material were stored for 24 hours in a buffer solution with a pH of 6.8. The remaining 12 samples were placed in a buffer with a pH of 3.0. All specimens were then subjected to a three media brushing abrasion (2,000 strokes) in an automatic brushing machine. Storage and brushing were performed three times. After 6,000 brushing strokes per specimen, the tape was removed. Brushing abrasion was measured with a computerized laser profilometer and statistically analyzed with ANOVA and Tukey's Standardized Range Test ($p \leq 0.05$). The highest brushing abrasion was found for the two carboxylate cements. The lowest brushing abrasion was found for one resin based material, Compolute Aplicap. With the exception of three resin-based materials, a lower pH led to a higher brushing abrasion.

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INTRODUCTION

With cast gold and ceramic restorations, the fabrication process leads to an inevitable space between tooth and restoration. The width of the gap depends on dentist's and dental technician's ability to provide precise preparation, impression technique, laboratory work and successful insertion of the restoration. Discussion around acceptable width of marginal gaps dates back

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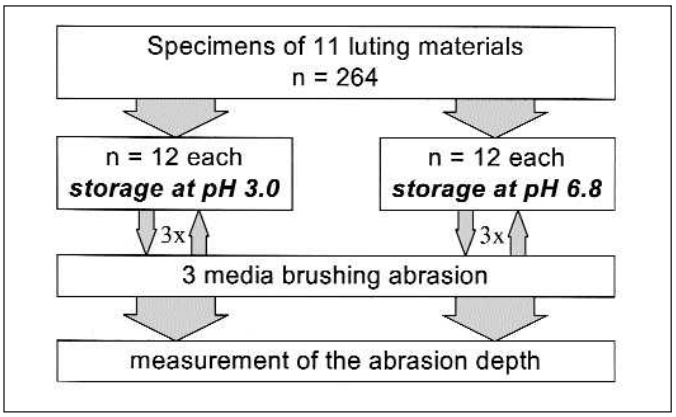

Figure 1. *Study design.*

to the beginning of restorative dentistry and continues today. However, Kydd & others (1996) found mean marginal gaps up to 74 µm width with 20 year-old cast gold crowns. With ceramic restorations, gap widths of about 100 µm (Gemalmaz & others, 1997) and up to 400 µm (Berg & Dérand, 1997) were detected. It is desirable for luting cements to withstand chemical irritants, mechanical wear and chemomechanical desintegration. For ceramic and composite inlays, a relationship between gap width and cement wear could be demonstrated, particularly for wider marginal openings. Moreover, a correlation between the type of cement and cement wear has been found (Shinkai & others, 1995; Kawai, Isenberg & Leinfelder, 1994). At buccally, occlusally, lingually or palatally located margins toothbrushing abrasion may play an important role for loss of luting cements in the gap.

A decreased pH may be present both at plaque-covered margins, and after erosive challenges. Millward & others (1997) have shown that after the consumption of an acidic solution pH values of 2 to 3 can be measured at palatal surfaces of anterior teeth. It can be presumed that a lower pH leads to higher abrasion values for restorative materials and luting cements but little information concerning these questions is available. Therefore, this study evaluated the brushing abrasion resistance of different dental luting materials under neutral and acidic conditions.

METHODS AND MATERIALS

Specimen Preparation

Figures 1 and 2 provide an overview of the study design. Two hundred and sixty four planoparallel cylinders 25 mm in diameter and 7 mm high were made of self-curing acrylic resin (Technovit 4071, Kulzer, Werheim, Germany). An axial bore of 10 mm diameter and 2 mm depth was drilled in each cylinder. Each of 24 molds was filled with one of the 11 investigated luting materials listed in Table 1. The materials were mixed and cured according to the manufacturers' instructions. Light curing

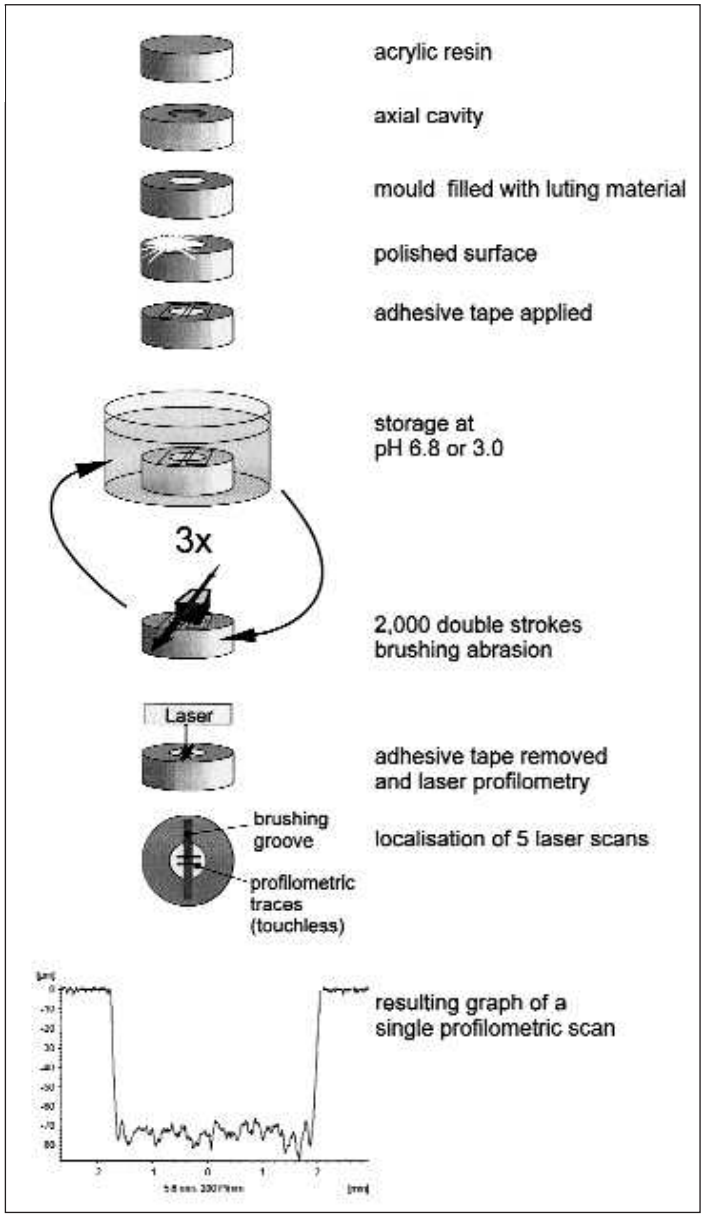

Figure 2. *Chronologic scheme of the experiments.*

of the light curing materials was performed with an Optilux 400 curing unit for 60 seconds per specimen (Demetron Research Corporation, Danbury, MA). All samples were stored in 100% relative humidity at 37°C for seven days. Afterwards, the specimens were ground flat with abrasive silicium carbide paper (Struers, Willich- Schiefbahn, Germany) up to FEPA 4000 using a water-cooled grinding device (Struers). The surfaces were then polished with a diamond spray of 3 and 1 µm grit (DP-Spray, Struers). The specimens were covered with adhesive tape (TESA, Beiersdorf, Hamburg, Germany) leaving a 4 mm wide oblong window on the cement surface. The exposed area of each specimen was subjected to brushing abrasion, as described later, whereas the covered area acted as a reference level for

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Table 1: *Investigated Materials SC* = self curing; LC** = light curing*

Category	Brand	System	Curing Mode	Manufacturer	Batch #
resin based materials	Compolute Aplicap	powder/liquid capsule for automatic mixing	SC*/LC**	ESPE Seefeld, Germany	CLA 1.0 FW0036583
	C&B-Metabond	paste/paste manual mixing	SC/LC	Parkell Farmingdale, NY, USA	70102
	Panavia 21	paste/paste manual mixing	SC/LC	Kuraray, Osaka, Japan	cat 0295 uni 0275
	Variolink Ultra	paste/paste manual mixing	SC/LC	Vivadent Schaan, Liechtenstein	900953
polyacid modified resin composite	Dyract Cem	powder/liquid manual mixing	SC/LC	Dentsply DeTrey Konstanz, Germany	opaque P:9711000020 L:9712000822
resin modified glass ionomer cement	Vitremer Luting Cement	powder/liquid manual mixing	SC/LC	3M Dental Products, St Paul, MN, USA	19970929
glass ionomer cements	Fuji I	powder/liquid manual mixing	SC	GC Europe, Haverlee, Belgium	P: 271161 L: 171061
	Ketac-Cem Aplicap	powder/liquid automatic mixing	SC	ESPE, Seefeld, Germany	FW0035664
carboxylate cements	Poly-F Plus	powder/liquid manual mixing	SC	Dentsply DeTrey Konstanz, Germany	9701000195
	Durelon Maxicap	powder/liquid automatic mixing	SC	ESPE, Seefeld, Germany	FW0036782
zinc phosphate cement	Harvard	powder/liquid manual mixing	SC	Richter & Hoffmann Berlin, Germany	P: 2122397004 L: 2121097002

the determination of lost material after the brushing abrasion.

Storage and Brushing Abrasion

The 24 specimens of each material were divided into two groups. Twelve specimens of each material were stored in a neutral buffer solution at pH 6.8 and 12 specimens were stored in an acidic buffer solution at pH 3.0 for 24 hours, respectively. The compositions of the buffer solutions have been described in a previous study (Attin & others, 1996 a) and are listed in Table 2. The samples were removed from the buffer solutions, cleaned under running tap water for 10 seconds and mounted in an automatic brushing machine for three media brushing abrasion (VDD Elektronik, Freiburg, Germany) as previously described in detail (Attin & others, 1997). The mounted specimens were covered with 20 ml of an abrasive slurry (Table 2) and subjected to a linear toothbrush abrasion movement of 2000 double strokes (back and forth movements) with a frequency of 100 per minute. For each specimen a new toothbrush of medium bristle stiffness (Medoral Clip, Fuchs Zahnforschung, Bensheim, Germany) and new slurry was used. The load applied was 2.75 N. Subsequently, the specimens were removed and stored for 24 hours in the respective buffer solutions and again subjected to an additional 2000 double strokes brushing abrasion. Finally after a third cycle of 24 hours storage and 2000 strokes of brushing abrasion, a total of 6000 double strokes was performed.

Measurements and Statistics

To determine wear, the adhesive tape was removed from the specimens, exposing the untreated reference areas adjacent to the brushing groove (Figure 2). Remnants of the glue were carefully removed with acetone. The relative depth of the brushing groove was determined by means of a PC-assisted laser profilometer (Micro-focus and UBSoft for Windows 1.704, UBM Messtechnik, Ettlingen, Germany). Five two-dimensional profilometric

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Table 2: *Composition of Buffer Solutions and Abrasive Slurry*	
buffer solution pH 3.0	0.015 M Na_2HPO_4 0.07 M NaCl 0.0218 M L(+)-lactic acid 0.01 M HCl for adjusting the pH at 3.0
buffer solution pH 6.8	0.01 M Na_2HPO_4 0.14 M NaCl 0.01 M HCl for adjusting the pH at 6.8
abrasive slurry	20 ml aqua dest 10 g toothpaste (Blendax Antibelag 3, Procter & Gamble, Schwalbach, Germany) 12 g pumice (medium grit, Hinrichs, Goslar, Germany)

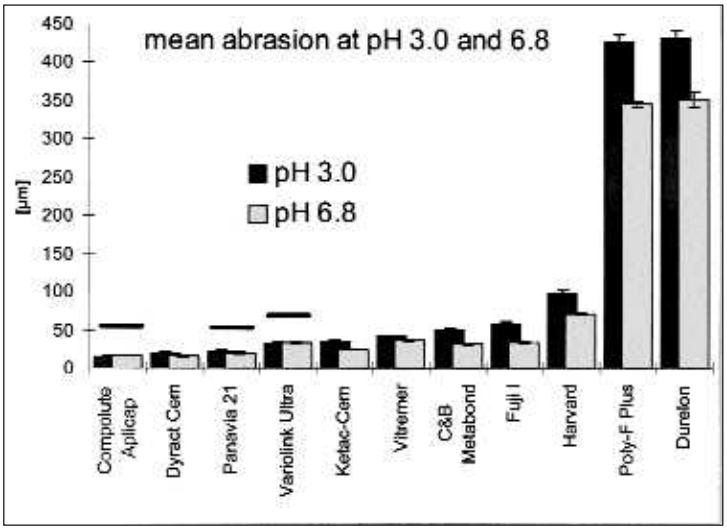

Figure 3. *Mean brushing abrasion (depth of the brushing groove) and standard deviations in µm of the investigated materials under acidic (pH 3.0) and neutral (pH 6.8) storage conditions. Means of the same material statistically insignificantly different between the two storage conditions are indicated with a horizontal bar.*

scans were performed for each specimen. The laser beam moved perpendicularily to the brushing direction. The five scans were conducted in 500 µm distance. The resolution of the laser scanning device is under 1 µm. From this data the mean difference between the abraded area and the original non-abraded surface, ie, the mean depth of the brushing groove of each specimen, was calculated. For statistical analysis the mean values of each experimental group (storage under neutral and acidic conditiones) for the respective tested materials was calculated and ANOVA and Tukey's Standardized Range Test were performed. Level of significance was set at $p \leq 0.05$.

RESULTS

Investigation results are shown in Table 3 and Figure 3. With the exception of the resin-based materials (Compolute Aplicap, Panavia 21 and Variolink Ultra), all tested materials showed a statistically significantly higher brushing abrasion under acidic storage conditions, compared with neutral storage conditions. The materials ranked similarly within each storage environment. Under both storage conditions, the statistically significantly highest brushing abrasion occurred with the two carboxalate cements Durelon Maxicap and Poly-F Plus. Under acidic storage conditions, the resin-based material (Compolute Aplicap) statistically showed the lowest brushing abrasion. Under neutral storage conditions, Compolute Aplicap and the polyacid-modified resin material (Dyract Cem) revealed the lowest statistically significant brushing abrasion.

DISCUSSION

Discussion of the Method

Dental material wear was investigated using several methods. Occlusal masticatory impact was mimicked with chewing simulators in two body wear

Table 3: *Mean Brushing Abrasion (depth of the brushing groove) and Standard Deviations (SD) in µm of the Investigated Materials. Materials with the Same Letter (Tukey group) Do Not Show Statistically Significant Differences.*

pH 6.8				pH 3.0			
Material	Mean [µm]	SD [µm]	Tukey group	Material	Mean [µm]	SD [µm]	Tukey group
Durelon Maxicap	352	10.53	A	Durelon Maxicap	432	9.78	A
Poly-F Plus	345	4.13	A	Poly-F Plus	429	7.99	A
Harvard	71	2.29	B	Harvard	99	2.65	B
Vitremer Luting	37	0.99	C	Fuji I	58	2.73	C
Variolink Ultra	33	1.51	D	C&B Metabond	52	1.73	D
Fuji I	33	1.86	D E	Vitremer Luting	43	1.29	E
C&B Metabond	31	1.46	E	Ketac-Cem Aplicap	36	0.99	F
Ketac-Cem Aplicap	24	1.06	F	Variolink Ultra	34	1.56	F
Panavia 21	20	1.63	G	Panavia 21	22	1.28	G
Compolute Aplicap	16	1.61	H	Dyract Cem	20	1.08	G
Dyract Cem	15	0.88	H	Compolute Aplicap	16	0.67	H

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experiments (Krejci & others, 1990; Attin & others, 1996 b) and three body wear experiments (De Gee & Pallav, 1994; De Gee, Pallav & Davidson, 1986; Pallav, Davidson & De Gee, 1988; Pelka & others, 1996). Since the margins of luted restorations are not only located in the occlusal area, wear at the palatal, lingual or vestibular sites may be caused by toothbrushing abrasion instead of occlusal masticatory impact. Therefore, this study performed a toothbrushing abrasion test based on a previous investigation (Attin & others, 1998).

Heath & Wilson (1974) reported that patients brush their teeth with 4.5 strokes per second. Supposing that a sextant is subjected to brushing for 20 seconds, 90 brushing strokes are applied per implementation. In this study, 6,000 brushing strokes were applied, representing approximately one to two months. Moreover, the abrasive capacity of the slurry was enlarged by adding medium-grit pumice. This ensures a measurable abrasion that is more pronounced compared to the abrasion caused by daily use of usual dentifrices containing silica as an abrasive. Using an original dentifrice without pumice and more storage brushing cycles could lead to a greater influence of the storage conditions. However, the method used revealed clear differences among different storage conditions.

When storing specimens in buffer solutions for at least three hours, much of the material lost could be due to the solution processes during that period. Investigations prior to this study demonstrated that the solubility of all materials under both storage conditions was below the threshold of measurability. It may be assumed that the method used is reliable for investigating the brushing abrasion of dental materials.

Discussion of the Results

Results of the study indicate an influence of the environmental pH and the chemical composition of the cements on the abrasion behavior. Only the resin-based materials, with the exception of C&B Metabond, do not show a higher abrasion at lower pH conditions. However, the acid-base setting materials and materials containing both, resin- and acid-base setting components (polyacid-modified resin composites and resin-modified glass-ionomer cements) are more susceptible to brushing abrasion at lower pH values. Ceramic restorations are very popular, as their appearance closely imitates that of natural teeth. The fabrication procedure of these restorations leads to marginal gaps, especially with CAD/CAM and machine milling systems (Berg & Dérand, 1997; Peters, Rinke & Schäfers, 1996). Hence this requires a gap filling luting material with adequate chemo-mechanical properties. Although the wear resistance of resin-based luting materials is superior to acid-base setting cements, the wear is higher compared to ceramic restorations or even luted composite restorations (Kunzelmann, Deigner & Hickel, 1993). Therefore, now as ever, a proper fit with small marginal gaps is important for ceramic restorations. Focusing on abrasion resistance under both neutral and acidic enviromental conditions, carboxylate and zinc phosphate cements are not suitable for luting purposes of restorations with marginal gaps. For those restorations, the resin-based materials Compolute Aplicap, Dyract Cem and Panavia 21 can be recommended.

CONCLUSIONS

Within the limitations of the experimental conditions, findings conclude:

1. Brushing abrasion of a) acid-base setting luting cements, b) resin-modified glass-ionomer luting cements and c) polyacid-modified resin-composite luting materials increases with a decreasing pH of the environment.
2. The environmental pH does not exert an influence on the brushing abrasion of resin based luting materials with exception of C&B Metabond.
3. The two carboxylate cements investigated demonstrated statistically significant highest brushing abrasion, whereas the resin-based luting material Compolute Aplicap showed statistically significantly lowest brushing abrasion.
4. For restorations with marginal openings, ie, ceramic restorations, the resin-based materials Compolute Aplicap, Dyract Cem and Panavia 21 can be recommended to reduce material loss due to brushing abrasion and wear.

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Marginal Seal of Resin-Modified Glass Ionomers and Compomers: Effect of Delaying Polishing Procedure After One-Day Storage

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Clinical Relevance

The marginal seal of resin-modified glass ionomers is enhanced by delaying polishing for one day. Delaying was not necessary for a compomer.

SUMMARY

This study evaluated the effects of polishing after one-day storage in water on the marginal gap formation around fillings using three resin-modified glass ionomers, one compomer, one conventional glass ionomer, and one micro-filled composite as a control. The study also examined the marginal gap and bond strength in Teflon cavities and the flexural strength of these restorative materials, which may influence the marginal gap formation.

Immediately after the setting procedure, the specimen was polished and a marginal gap of approximately 10-25 micrometers was observed regardless of the type of restorative material used. In contrast, we observed no gap or a 1-2 micrometer gap width when the specimens were polished after one-day storage. Only Dyract did not show this pattern. Statistical difference was observed between immediately polishing and polishing after one-day storage in all materials except Dyract.

Hygroscopic expansion, bond strength and flexural strength play important roles in reducing the marginal gap in tooth cavities filled with two types of glass-ionomer restorative materials. In contract, these properties did not play important roles in reducing the marginal gap width for Dyract.

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INTRODUCTION

Two types of combination materials have been developed in the last six years. The first is a resin-modified glass ionomer, or RMGI. It is unlike a light-cured resin composite, a conventional glass ionomer or CGI; it has a dual setting reaction consisting of an acid-base reaction and a photochemical polymerization process. The final set materials are described as having a complex structure in which glass particles are sheathed in a matrix consisting of two networks, one derived from the glass ionomer, the other from the resin (Wilson, 1990; Mitra, 1991). In these dual-setting systems, the resin reinforcement gives higher mechanical strength (Uno,

Finger & Fritz, 1996; Irie & Suzuki, 1999) and higher bond strength to tooth surfaces compared to CGIs. The RMGI claims to have improved marginal seal by hygroscopic expansion (Sidhu, Sherriff & Watson, 1997) and improved bonding ability (Fritz, Finger & Uno, 1996a, b; Irie & Suzuki, 1999) after storage in water. The second new material is a polyacid-modified resin composite, either a single- or two-component material containing one or both of the essential components of a glass ionomer. However, the components do not react as part of the setting process (McLean, Nicholson & Wilson, 1994). It is referred to as a "Compomer" to reflect the composite/glass ionomer derivation of its product. It consists of a resin matrix and a fluoroaluminosilicate glass filler. However, it undergoes no dimensional change by hygroscopic expansion (Irie & Nakai, 1998). Therefore, it may not improve the marginal seal. The monomer in resin matrix ionizes following water uptake during storage after light-activation. The released hydrogen ions then react with the glass filler to initiate an acid-base reaction. Ionic cross-linking also occurs and fluoride is released (Hammesfahr, 1994). Therefore, it may improve the marginal seal by enhancing the bond ability.

A flexural test was used to assess the mechanical properties of CGIs or RMGIs because this testing has been previously carried out to evaluate the mechanical strength of brittle restorative materials (Momoi & others, 1995; Irie & Nakai, 1998). The relationship between shear-bond strength of silver-added glass ionomers and flexural strength was statistically significant (Irie & Nakai, 1988). The RMGIs and CGIs claim to have improved marginal seal because of an increase in the flexural strength after light-activation and setting (Irie & Suzuki, 1999).

In this study we, therefore, evaluated the effect of storage in water on the marginal gap formation using RMGIs and a compomer. We also examined the marginal gap in Teflon cavities, and the bond strength and flexural strength because these properties may influence the marginal gap formation.

METHODS AND MATERIALS

The basic properties of three RMGIs, one compomer, one CGI and one micro-filled composite are summarized in Tables 1 and 2. All processing of these materials was carried out according to the manufacturer's instructions. Capsules of Photac-Fil were triturated using a high-speed mixer (Silamat, Vivadent, Schaan, Liechtenstein) for 15 seconds. For light activation of the priming or sealing agents and the restorative materials, a curing unit (New Light VL-II, GC, Tokyo, Japan; irradiated diameter: 13 mm) was used. Human premolars extracted for orthodontic reasons were used for the experiment. After extraction, each tooth was immediately stored in cold distilled water at 4°C for one to two months before testing. For each material and storage period, 10 specimens were made. All procedures, except cavity preparation and

Table 1: *Restorative Materials Investigated*

Material	Manufacturer	Batch #	Type (Powder/Liquid)/Components
Fuji II LC	GC Corp Tokyo, Japan	P: 030921 L: 250721	Resin-modified GIC (3.0g/l.0g) P: fluoroaluminosilicate glass L: copolymer of acrylic and malei acid, HEMA, water
Vitremer	3M Dental Products, St Paul, MN USA	19930203	Resin-modified GIC (2.5g/l.0g) P: fluoroaluminosilicate glass L: polyalkenoate coplymer, HEMA, water
Photac-Fil	ESPE GmbH Seedfeld Germany	X033	Resin-modified GIC (Precapsulated) P: fluoroaluminosilicate glass L: copolymer of maleic acid and acrylic acids monomers, oligomers, water
Dyract	DeTrey/Dentsply Konstanz Germany	B 930776	Compomer fluoroaluminosilicate, polyacrylic acid, UDMA
Fuji II	GC Corp Tokyo, Japan	P: 300302 L: 120901	Conventional GIC (2.7g/l.0g) P: fluoroaluminosilicate glass L: copolymer of acrylic and maleic acids, polybase carboxylic acid, water
Silux Plus	3M Dental Products St Paul, MN USA	1DW1	Micro-filled resin composite Colloidal silica (38 vol%), Bis-GMA, TEGMA

Key: GIC, glass-ionomer cement; HEMA, 2-Hydroxyethyl methacrylate; UDMA, urethane dimethacrylate; Bis-GMA, bisphenol A glycidyl methacrylate; TEGDMA, tri-ethylene-glycol dimethacrylate.

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Table 2: *Treating Agents Investigated*

Material	Manufacturer	Batch #	Components and Surface Treatment
Dentin Conditioner	GC Corp Tokyo, Japan	151021	Polyacrylic acid, water Apply with brush 20 seconds ➔ rinse 15 seconds ➔ gently dry 5 seconds
Vitremer Primer	3M Dental Products St Paul, MN USA	35	HEMA, maleic acid in aqueous solution, ethyl alcohol Apply 30 seconds ➔ gently dry 5 seconds ➔ light cure 20 seconds
Ketac-Conditioner	ESPE GmbH Seefeld Germany	0002	Polyacrylic acid, water Apply with brush 10 seconds ➔ rinse 15 seconds ➔ gently dry 5 seconds
Dyract-PSA	DeTrey/Dentsply Germany	931020	PENTA, TEGDMA, acetone Apply 30 seconds ➔ gently dry 5 seconds ➔ light cure 10 seconds
Scotchbond Multi-Purpose	3M Dental Products St Paul, MN USA	Etchant(2AC) Primer (2AC) Adhesive(2AB)	10% maleic acid, water HEMA, polyalkenoic acid, copolymer, water Bis-GMA, HEMA Etch 15 seconds ➔ rinse 15 seconds ➔ gently dry 5 seconds ➔ Apply with brush (Primer) gently dry 5 seconds ➔ Apply with brush (Adhesive) light cure 20 seconds

Key: HEMA, 2-hydroxtethyl methacrylate; PENTA, dipentaerythritolpenta-acrylatemonophosphate; TEGDMA, tri-ethylene-glycol dimethacrylate; Bis-GMA, bisphenol A glycidyl methacrylate

mechanical testing, were performed in a thermo-hygrostatic room kept at 23±0.5°C and 50+2% relative humidity.

Marginal Gap in Tooth Cavity

Each tooth was embedded in slow setting epoxy resin (Epofix Resin, Struers, Copenhagen, Denmark). A flat surface of enamel was obtained by grinding the tooth with wet silicon carbide paper (#220). Then, a cylindrical cavity was prepared with a tungsten carbide bur (200,000-rpm) and a fissure bur (8,000-rpm) under wet conditions to a depth of approximately 1.5 mm with a diameter of 3.5 mm. One cavity was prepared in each tooth on the enamel surface of the crown. In total, cavities in 120 teeth were prepared for this study.

The prepared cavity surface was treated with the conditioner/primer according to each manufacturer's instructions. Dentin Conditioner and Ketac Conditioner were applied for 20 and 10 seconds, respectively, and rinsed with water. Vitremer Primer was applied for 30 seconds, air dried and light cured for 20 seconds. An ample amount of Dyract-PSA was applied and left undisturbed for 30 seconds. Excess solvent was removed by compressed air. The light-curing time was 10 seconds. A second layer of Dyract-PSA was applied with a brush. Etchant was applied for 15 seconds, rinsed and air-dried. Primer was applied and air-dried, following Adhesive, which was photocured for 10 seconds. The same conditioning/priming pretreatment was performed on enamel as on dentin.

The cavity was filled with mixed materials using a syringe tip (Centrix C-R Syringe System, Centrix, Connecticut) and covered with a plastic strip and hardened. Fuji II LC, Vitremer, Photac-Fil, Dyract and Silux Plus were exposed to a visible light source with irradiation time of 20 seconds, 40 seconds, 20 seconds, 40 seconds and 40 seconds, respectively. Fuji II was stored in an incubator at 37°C and 100% relative humidity for four minutes after mixing. The surface was polished immediately after light-activation or setting, or after storage in distilled water at 37°C for one day. The excess filling material was removed by wet grinding with silicon carbide paper (#1000), followed by polishing with linen with an aqueous slurry of 0.3 µm aluminum oxide (Alpha Micropolish, Buehler Ltd, Chicago, IL) and through rinsing with distilled water. Then the restoration margin was inspected under a light microscope (X1000, Measurescope, MM-11, Nikon, Tokyo, Japan). The maximum gap width and the opposing width between the material and the cavity wall were measured by using an optical microscope as previously described (Munksgaard, Irie & Asmussen, 1985; Irie & Suzuki, 1999). The marginal gap was expressed as the sum of these two values.

Marginal Gap in Teflon Cavity

Since a Teflon material does not react with a filled material, it was used as a mold to measure a degree of the setting shrinkage (immediately after set) and the hygroscopic expansion (after one-day storage in water). To estimate the degree of setting shrinkage and hygroscopic expansion and compare the marginal gap width in a tooth cavity directly, a Teflon mold of the same diameter and depth was prepared. The prepared Teflon mold was placed on a silicone oil-coated glass plate, as

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a glass plate does not react or bond to the filled material. Making and measuring a specimen involved the same procedure as described above.

Shear Bond Strengths to Enamel and to Dentin

The bond strength to enamel and dentin, which comprise the cavity wall, was measured to evaluate the effect of bond ability between the filling material and the cavity. The specimen was a human premolar embedded in slow-setting epoxy resin (Epofix Resin, Struers, Copenhagen, Denmark). A flat surface of enamel or dentin was obtained by grinding the tooth with wet silicon carbide paper (#1000). The prepared surface was treated with the conditioner/primer according to each manufacturer's instructions as described above. The mixed material was placed in a Teflon mold (3.6-mm in diameter, 2.0-mm in height) set on the enamel or dentinal surface and hardened as described above. The obtained specimen was thus mounted on a testing machine (Autograph, DCS-200, Shimadzu, Kyoto, Japan), and shear stress was applied at a cross-head speed of 0.5 mm/min. In this experiment, measurements were carried out under two conditions: immediately after the setting procedure and after the specimen was kept in distilled water at 37°C for one day. After the shear-bond strength measurement, all the failed specimens were analyzed under a light microscope (X4) (SMZ-10, Nikon, Tokyo, Japan) to ascertain the nature of fractures.

Flexural Strength

A Teflon mold was used to make the specimen (25x2x2 in mm) for the flexural strength measurement. The material was cured in three overlapping sections, each cured for 40 seconds. The Fuji II was stored at 37°C and 100% relative humidity for four minutes after mixing. The flexural strength was measured using the three-point bending method with a 20 mm-span and loading speed of 0.5 mm/min, outlined in ISO 9917-2 (1996). In this experiment, as well, measurements were carried out under two different conditions: immediately after the setting procedure and after storage of the specimen in distilled water at 37°C for one day.

The results were analyzed statistically using Mann-Whitney U-test, Duncan's New Multiple-Range Test, Duncan's New Multiple-Range Test (Conover & Iman, 1981), *t*-Test or Complex Chi-Square Test

Table 3: *Effect of Polishing Period on Gap Width in Enamel Margin*

Material	Gap Width (Mean ± SD, μm)		alpha value*
	Immediately	After one-day storage	
Fuji II LC	8.7 ± 1.7 (0) A	0 (10) B	<0.05
Vitremer	25.3 ± 4.8 (0)	0.4 ± 1.0 (8) B C	<0.05
Photac-Fil	11.5 ± 2.2 (0) A	0.1 ± 0.3 (9) B	<0.05
Dyract	9.7 ± 2.2 (0) A	9 .1 ± 4.6 (1)	NS
Fuji II	14.8 ± 2.1 (0)	0.6 ± 1.3 (8) B C	<0.05
Silux Plus	9.7 ± 3.3 (0) A	1.8 ± 2.2 (5) C	<0.05

Number of specimen: 10, ( ): Number of gap-free specimens
Values with same letters were not significantly different by Duncan's New Multiple-Range Test (Conover & Iman, 1981) (p>0.05)
*: Mann-Whitney U-Test
NS: Not significantly different by Mann-Whitney U Test (α>0 05)

Table 4: *Effect of Polishing Period on Gap Width in Teflon Mold*

Material	Gap width (Mean ± SD, μm)		p value*
	Immediately	After one-day storage	
Fuji II LC	29.1 ± 4.0 (14)	6.2 ± 1.3 (21) D	< 0.001
Vitremer	35.1 ± 5.0 (14) A	6.9 ± 2.9 (42) D	< 0.001
Photac-Fil	22.7 ± 4.4 (19) B	6.6 ± 2.7 (41) D	< 0.001
Dyract	17.0 ± 4.1 (24) C	15.3 ± 2.8 (18)	NS
Fuji II	35.1 ± 6.6 (l9) A	9.3 ± 1.4 (15) E	< 0.001
Silux Plus	20.7 ± 4.1 (20) B C	7.5 ± 2.0 (27) D E	< 0.001

Number of specimen: 10, ( ): Coefficient of variation (%)
Values with same letters were not significantly different by Duncan's New Multiple-Range Test (p>0.05)
*: *t*-Test
NS: Not significantly different by *t*-Test (p>0.05)

RESULTS

Table 3 summarizes the data for the marginal gap observed in the tooth cavities in two conditions. When the specimen was polished immediately after the setting procedure, we observed a marginal gap of approximately 10-25 micrometers regardless of the type of restorative materials used. In contrast, except for Dyract, we observed either no gap or a 1-2 micrometer gap width when the specimen was polished after storage in water for one day. Statistical differences were observed between

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Table 5: *Effect of Storage in Water on Shear Bond Strength to Enamel*

Material	Shear bond strength (Mean ± SD, MPa)		p value*
	Immediately	After one-day storage	
Fuji II LC	2.60 ± 0.56 (22) A	13.80 ± 3.97 (29) C	< 0.001
Vitremer	3.89 + 0.72 (19) B	6.44+ 1.89 (29) D	< 0.001
Photac-Fil	3.48 ± 0.95 (27) A B	14.10 ± 5.24 (37) C	< 0.001
Dyract	8.66 ± 1.82 (21)	9.94 ± 3.90 (39)	NS
Fuji II	0.71 ± 0.23 (32)	3.78 ± 0.63 (17) D	< 0.001
Silux Plus	6.83 ± 2.03 (30)	18.25 ± 5.03 (28)	< 0.001

Number of specimen: 10, ( ): Coefficient of variation (%)
Values with same letters were not significantly different by Duncan's New Multiple-Range Test (p>0.05).
*: *t*-Test
NS: Not significantly different by *t*-Test (p>0.05)

Table 6: *Analysis of Fracture Mode Corresponding to Table 5*

Material	Number of each fracture mode		p value*
	Immediately	After one-day storage	
Fuji II LC	(AF: 8, MF: 2, CF: 0)	(AF: 0, MF: 10, CF: 0)	<0.005
Vitremer	(AF: 7, MF: 3, CF: 0)	(AF: 5, MF: 5, CF: 0)	NS
Photac-Fil	(AF: 0, MF: 1, CF: 9)	(AF: 0, MF: 1, CF: 9)	NS
Dyract	(AF: 1, MF: 9, CF: 0)	(AF: 4, MF: 3, CF: 3)	<0.025
Fuji II	(AF: 4, MF: 6, CF: 0)	(AF: 4, MF: 5, CF: 1)	NS
Silux Plus	(AF: 0, MF: 1, CF: 9)	(AF: 0, MF: 0, CF: 10)	NS

Number of specimens: 10, AF: Adhesive fracture at bonding site
MF: Mixed fracture, CF: Cohesive fracture
*: Complex Chi-Square Test
NS: Not significantly different by Complex Chi-Square Test (p>0. 05)

polishing immediately and polishing after one-day storage, except for Dyract.

Table 4 summarizes the marginal gap width between the various restorative materials and Teflon molds under two conditions. The gap width under each condition was wider than that obtained using the tooth cavity. The data for polishing after one-day's storage was significantly better compared to that for polishing immediately, except for Dyract. An apparent correlation of the marginal gap in tooth cavity with the marginal gap in Teflon mold was observed for the condition after one-day storage (r=0.95, p<0.01) when analyzed by Pearson Product-Moment Correlation.

Tables 5 and 6 summarize the shear bond strength to the enamel surface and the mode of fracture, respectively. Greater bond strength was obtained after storage for a day than that immediately after setting, except for Dyract. Fuji II LC and Photac-Fil showed a value between a micro-filled composite and a CGI in the two conditions. In the case of Dyract, there was no significant difference between the values measured immediately and after a one-day storage. Statistical difference of the fracture modes was not observed between polishing immediately and polishing after one-day storage, except for Fuji II LC and Dyract. In the Fuji II LC group, mixed failure was more frequently observed after the one-day storage. On the other hand, in the Dyract group, adhesive and cohesive failures were more frequently observed.

Tables 7 and 8 summarize the shear bond strength to the dentin surface and the mode of fracture, respectively. In the Fuji II LC, Vitremer and Fuji II cases, greater bond strength was obtained after the one-day storage period than that immediately after setting. After one-day storage, two RMGIs (Fuji II LC and Vitremer) showed significantly greater value than those of the CGI and the micro-filled composite reference materials, Fuji II and Silux Plus. In the case of Dyract, there was no significant difference between bond strength values immediately and after one-day storage, as mentioned above. In the three groups (Fuji II LC, Vitremer and Dyract), statistical differences between the fracture modes were not observed between polishing immediately and polishing after one-day's storage. On the other hand, in the Photac-Fil group, mixed and cohesive failures were more frequently observed after one-day storage. In the Fuji II group, the proportion of cohesive fractures increased with the value of the bond strength to the dentin surface. In the Silux Plus group, adhesive failure was more frequently observed after one-day storage.

Table 9 summarizes the flexural strength under two conditions. When the specimens were stored in water for a day, all materials showed significantly greater value than when the specimens were measured immediately after setting. The RMGIs, except Photac-Fil, showed greater flexural strength than the Fuji II after

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Table 7: *Effect of Storage in Water on Shear Bond Strength to Dentin*

Material	Shear bond strength (Mean ± SD, MPa)		p value*
	Immediately	After one-day storage	
Fuji II LC	2.05 ± 0.51 (25) A	12.99 ± 2.04 (16) B C	<0.001
Vitremer	3.93 ± 0.67 (17)	12.27 ± 2.89 (24) B	<0.001
Photac-Fil	0.52 ± 0.24 (46) A	1.13 ± 1.73 (153) D	NS
Dyract	10.49 ± 3.52 (34)	15.64 ± 5.62 (36) C	NS
Fuji II	0.50 ± 0.11 (22) A	4.24 ± 1.05 (25) D	<0.001
Silux Plus	5.97 ± 2.41 (40)	8.63 ± 5.47 (63)	NS

Number of specimen: 10, ( ): Coefficient of variation (%)
Values with same letters were not significantly different by Duncan s New Multiple-Range Test (p>0.05).
*: t-Test
NS: Not significantly different by t-Test (p>0.05)

Table 8: *Analysis of Fracture Mode Corresponding to Table 7*

Material	Number of each fracture mode		p value*
	Immediately	After one-day storage	
Fuji II LC	(AF: 0, MF: 0, CF: 10)	(AF: 0, MF: 0, CF: 10)	NS
Vitremer	(AF: 0, MF: 1 , CF: 9)	(AF: O, MF: 5, CF: 5)	NS
Photac-Fil	(AF:10, MF: 0, CF: 0)	(AF: 2, MF: 6, CF: 2)	<0.001
Dyract	(AF: 0, MF: 1, CF: 9)	(AF: 0, MF: 2, CF: 8)	NS
Fuji II	(AF: 0, MF: 10, CF: 0)	(AF: 0, MF: 0, CF: 10)	<0.001
Silux Plus	(AF: 0, MF: 1, CF: 9)	(AF: 4, MF: 4, CF: 2)	<0.01

Number of specimens: 10, AF: Adhesive fracture at bonding site
MF: Mixed fracture, CF: Cohesive fracture
*: Complex Chi-Square Test
NS: Not significantly different by Complex Chi-Square Test (p>0.05)

one-day storage. Dyract showed the highest value of all materials under two conditions.

DISCUSSION

This study clearly demonstrated that the polishing of four filled glass ionomers (Fuji II LC, Vitremer, Photac-Fil and Fuji II) should not be performed immediately after the filling and setting procedure. It should be delayed to a later time to prevent marginal gap formation between the material and the tooth cavity. In contrast to the marginal gap of approximately 10-25 micrometers, when the specimen was polished immediately after setting, the gap was zero or almost zero when the specimen was polished after storage in water for a day. RMGI or CGI shrinks during the setting reaction. A marginal gap was formed, as the adhesion between the tooth cavity and glass ionomer did not resist the stress formed by the cement shrinkage (Feilzer, de Gee & Davidson, 1988; Sidhu, 1994). One reason for this dependence of the marginal gap on the storage period may be the hygroscopic expansion of the glass ionomer because an apparent correlation of the marginal gap in tooth cavity with the marginal gap in Teflon mold was observed for the condition after one-day storage (n=6, r=0.95, p<0.01). This effect is reported for the uptake of water by the matrix of resin-modified glass ionomers forming a poly-HEMA complex (Wilson, 1990). Also, CGI forms a hydrogel of calcium and aluminum polyacrylates by uptake of water (Wilson & McLean, 1988). After one-day water storage the curing contraction stresses of the materials are effectively compensated for or even converted into expansion stress due to water uptake and swelling (Feilzer & others, 1995). Water absorption of RMGIs and CGIs reportedly affects cavity adaptation and reduces microleakage (Irie & Nakai, 1987; Fritz, Finger & Uno, 1996b). Although the hygroscopic expansion may not be enough to compensate for the setting shrinkage, it plays an important role in reducing the shrinkage caused by the cement setting reaction and thus improves the marginal seal (Sidhu, Sherriff & Watson, 1997).

The marginal gap measured using the Teflon mold showed a similar pattern, with respect to the polishing condition or the type of glass ionomer, to that obtained using the tooth cavity, as mentioned above. However, the marginal gap in the Teflon mold was wider than the corresponding marginal gap obtained using the tooth cavity. Cement filling in a Teflon mold is not susceptible to interaction with the cavity due to the non-reactivity of Teflon. The marginal gap observed even after the specimen was stored in water for a day indicated that the hygroscopic expansion does not fully compensate for the shrinkage caused by the setting reaction. The smaller marginal gap observed in the tooth cavity than in the Teflon mold clearly demonstrated that the adhesion between the cement and cavity has an important influence on the marginal gap (Irie & Suzuki, 1999).

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Table 9: *Effect of Storage in Water for One Day on Flexural Strength*

Material	Flexural strength (Mean ± SD, MPa)		p value*
	Immediately	After one-day storage	
Fuji II LC	41.7 ± 4.6 (11)	59.2 ± 8.3 (14)	<0.001
Vitremer	7.2 ± 2.2 (31) A	73.0 ± 11.3 (15) B	<0.001
Photac-Fil	32.1 ± 2.8 (9)	40.0 ± 6.2 (16) C	<0.01
Dyract	74.3 ± 8.1 (11)	129.5 ± 20.3 (16)	<0.001
Fuji II	6.0 ± 1.3 (22) A	33.7 ± 9.7 (29) C	<0.001
Silux Plus	59.1 ± 7.4 (13)	76.1 ± 10.4 (14) B	<0.001

Number of specimen: 10, ( ): Coefficient of variation (X%)
Values with same letters were not significantly different by Duncan's New Multiple-Range Test (p>0.05)
*: t=Test

This study showed that the values of the bond strength and the flexural strength of one-day storage were significantly higher than those measured immediately for the four filled glass ionomers (Fuji II LC, Vitremer, Photac-Fil and Fuji II). It has been reported that the bond strength of a RMGI has a close relationship with its mechanical strength (Mitra, 1991; Hinoura, Miyazaki & Onose, 1991). The shear bond strength of a silver-added glass ionomer was correlated with its flexural strength (Irie & Nakai, 1988). Therefore, the flexural strength has influence on marginal gap formation. In this experiment, we found close relationships among the flexural strength of the cement, the shear bond strength to enamel and dentin and the fracture mode, such that the marginal gap became smaller with increasing bond strength, proportioned rate of mixed and cohesive fractures and flexural strength of the cement. It is not unexpected that the cement shows higher bond and mechanical strengths when fully set than during the setting reaction. It is suggested the bond ability to the tooth substrate increases with the development of the glass ionomer/tooth substrate interaction during storage in water, and that the cohesive strength of the cement itself improves with the setting process. It is reported that the pH, an index of the degree of the hardening reaction of set glass ionomer, is lower at the initial stage regardless of the type of cement, that is, conventional or resin-modified glass ionomers. The pH value of the set cement gradually increases for 24 hours (Tosaki & Hirota, 1994; Anusavice, 1996). Therefore, it can be presumed that completing of the setting reaction of a RMGI or CGI requires 24 hours. Thus, 24 hours are required until a RMGI or CGI has adequate mechanical strength, which has a close relationship with the bond strength. It has a dual setting reaction: one is light-initiated cross-linking of methacrylate groups similar to the setting of light-cured resin composites, and the other is an acid-base reaction like that of a CGI (Wilson, 1990; Mitra, 1991). The results of this investigation support previous reports that the RMGI has higher bond strength to enamel and to dentin and higher flexural strength than CGI (Mitra, 1991; Hinoura, Miyazaki & Onose, 1991; Irie & Suzuki, 1999).

The very low bond values for Photac-Fil after one-day storage may be due to fracturing of early locally debonded areas. It is possible that exposure of the Photac-Fil surface to water immediately after the end of light activation may have a similar adverse effect on setting, as commonly found with CGI after early water exposure. Other investigations have also reported poor bonding capacity of Photac-Fil with Ketac Conditioner (Sidhu & Watson, 1995; Fritz, Finger & Uno, 1996a,b).

Vitremer showed a lower bond value to enamel after one-day storage. A failure site after debonding showed a mixed failure of Vitremer bonded to enamel. The other report showed the same trend (Fritz, Finger & Uno, 1996a). Vitremer had a low initial shear bond strength to enamel (24 hours), although it had a higher bond value (14 MPa) at the long testing times (1-Mon, 3-Mon and 6-Mon).

This study demonstrated that delaying polishing of Dyract for a day does not prevent a marginal gap between the material and the tooth cavity. The marginal gap measured using the Teflon mold showed a similar pattern with respect to the polishing condition to that obtained using the tooth cavity. However, the marginal gap in the Teflon mold was wider. The marginal gap observed even after the specimen was stored in water for a day indicated that the hygroscopic expansion does not fully compensate for the shrinkage caused by the setting reaction. The smaller marginal gap observed in the tooth cavity compared to the Teflon mold clearly demonstrated that the adhesion between Dyract and cavity has an important influence on the marginal gap. The degree of hygroscopic expansion of Dyract was smaller than that of RMGIs because the composition of Dyract is similar to the resin composite system (Hammesfahr, 1994; Irie & Nakai, 1998).

This study showed that the values of the bond strength to enamel and dentin measured after one-day storage were not significantly higher than those measured immediately for Dyract, although the values of the flexural strength after one-day storage were significantly higher than those measured immediately. Since no micro-mechanical interlocking with conditioned

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enamel is available when Dyract-PSA is used, low shear bond strength to enamel was shown even after storage for 24 hours (Fritz, Finger & Uno, 1996a). However, higher mechanical strength of Dyract was shown compared with that of RMGIs (Uno, Finger & Fritz, 1996). The novel acid monomer of the compomer contains two acidic carboxylate groups and two polymerizable methacrylate groups, enabling free radical polymerization by light curing and acid-base reaction if water is present (Hammesfahr, 1994). Half the debonded specimens of Dyract bonded-to-enamel showed adhesive failure. It was shown that the bond strength of Dyract did not have a close relationship with its mechanical strength. The flexural strength of Dyract appeared to have no effect on marginal gap formation.

This study showed that the value of the bond strength to enamel of Silux Plus, measured immediately, was low (only 6.83 MPa) and that the majority of debonding was cohesive. It was thought that since the debonding was within the adhesive itself or at the interface between the adhesive and the composite, it might be because the adhesive could not be polymerized sufficiently with an irradiation time of only 10 seconds.

In this study the pretreatment by a tooth conditioner presented insufficient bonding to the tooth substrate. In the previous report (Irie & Suzuki, 1999), tooth conditioner was not used to simplify clinical procedure.

It is advisable not to place and polish the restoration at one appointment. We recommend that the prepared cavity be filled at the first appointment, then polished at the next appointment (Irie & Suzuki, 1999).

CONCLUSIONS

When the specimen was polished immediately after the setting procedure, marginal gaps of approximately 10-25 micrometers were observed regardless of the type of restorative material. In contrast, we observed no gap or a 1-2 micrometer gap width when the specimen was polished after one-day storage, except for Dyract. The efficacy of delaying the polishing procedure after one-day storage on a RMGI and a CGI was shown.

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Effect of Dentin Deproteinization on Microleakage of Class V Composite Restorations

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Clinical Relevance

The formation of gaps occurred at the dentin/cementum margins of Class V restorations regardless of the presence of a hybrid layer.

SUMMARY

The role of the collagen fibers in dentin adhesion has not clearly been established. Therefore, this laboratory study evaluated the microleakage at resin-dentin and resin-enamel interfaces of Class V composite restorations after etching enamel and dentin with phosphoric acid (H_3PO_4) or after etching with H_3PO_4 followed by deproteinization with 5% sodium hypochlorite (NaOCl) to prevent the formation of a hybrid layer. Ten extracted human molars were used to prepare standardized Class V cavities on both buccal and lingual surfaces. The teeth were randomly divided in two groups: 1) Class V cavities that were etched with H_3PO_4 for 15 seconds; b) Class V cavities that were etched with H_3PO_4 for 15 seconds followed by collagen removal with 5% NaOCl for two minutes. The cavities were restored using the Prime & Bond 2.1 bonding system and TPH resin composite. The specimens were stored in water for 24 hours at 37°C and thermocycled 500 times between water baths kept at 5°C and 55°C. After thermocycling, specimens were immersed in a 0.5% aqueous solution of basic fuchsin for 24 hours. Three longitudinal sections of each restoration were obtained and examined with a stereomicroscope for qualitative evaluation of microleakage. The data were statistically analyzed by Mann-Whitney U and Wilcoxon matched pairs signed ranked tests. Extra specimens were analyzed with the scanning electron microscope (SEM). Occlusal margins (enamel margins) resulted in statistical lower degree of leakage than gingival margins (dentin/cementum margins) in both treatment groups. For each type of margin, there were no statistically significant differences between the etched and the etched and deproteinized groups. Under the SEM, occlusal surfaces showed no detachment between enamel and dentin, while dentin/cementum resulted in gap formation.

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INTRODUCTION

A major problem in restorative dentistry is that dental materials do not adhere efficiently to natural tooth

structure. As a result, marginal leakage can allow the ingress of bacteria and salivary components, causing pulp damage, marginal staining and secondary caries (Asmussen, 1985).

Another problem related to composite restorations is the variability of the different substrates. Enamel is a reliable substrate for bonding, but bonding to dentin remains less reliable and predictable. Even with the introduction of more advanced dentin bonding systems, microleakage has been reduced but not eliminated (Mandras, Retief & Russell, 1993). Marginal discoloration, recurrent caries lesions and postoperative hypersensitivity are the most frequent outcomes of the penetration of oral fluids and bacteria through gaps formed within the restoration/cavity interface toward the pulp (Perdigão & others, 1996).

A pertinent factor in achieving satisfactory adhesion of composite resins to dentin is the way the dentin surface is treated before an adhesive is applied. Etching of dentin removes hydroxyapatite, leaving the collagen fibers without support except for that caused by the water contained within the dentin (Hansen & Asmussen, 1997). The infiltration of a resin monomer into chemically conditioned dentin is considered essential for improving bonding at the resin/tooth interface (Gwinnett, 1993). New one-bottle adhesives, dissolved in acetone, alcohol or water solvent, diffuse into the outer few micrometers of the tissue rendered porous by acidic conditioning (Gwinnett, 1994a). The hydrophilic monomers that compose these adhesives may become micro-mechanically interlocked with the network of exposed collagen fibers by forming a mixed structure with collagen fibers surrounded by resin and residual hydroxyapatite crystals (Van Meerbeeck & others, 1993). This formation was first described as the "hybrid layer" (Nakabayashi, Kojima & Masuhara, 1982; Nakabayashi, Nakamura & Yasuda, 1991). The manufacturers of simplified dentin adhesives recommend the application of their adhesive materials on moist dentin because the spatial alteration that occurs upon drying demineralized dentin may prevent the monomers from penetrating the labyrinth of nano-channels formed by dissolution of hydroxyapatite crystals (Eick & others, 1997). The application of adhesives on moist dentin is facilitated by incorporating organic solvents, such as acetone or ethanol, in the composition of most dentin adhesives between collagen fibers. The solvent can dislocate water from the dentin surface and from the moist collagen network, thus promoting the infiltration of resin monomers through the nano-spaces of the dense collagen web. This wet-bonding technique has been repeatedly shown to enhance bond strengths (Kanca 1992a, Gwinnett, 1992; Perdigão, Swift & Cloe 1993). After conditioning, the dentin should be lightly dried with an air syringe until the surface is slightly glossy. However, no excess water should remain on the tooth surface because its high water content places severe limitations on resin infiltration.

Aqueous-based adhesives can also be used when the dentin has been desiccated inadvertently. In this case, the aqueous components of the solvent rehydrates the dentin tissue, thus the collagen network becomes raised, enhancing the bonding mechanism (Nakabayashi & Pashley, 1998). Otherwise, adhesives that contain highly volatile solvents, such as acetone, may displace surface moisture and better serve to carry the primer monomers into the micro-porosities of the exposed collagen network (Gwinnett, 1994a).

The removal of collagen fibers with a deproteinizing material would facilitate the access of the adhesive resins to a substrate that is more permeable (or penetrable) (Inaba & others, 1995) and less sensitive to water content.

Therefore, this study evaluated the microleakage of Class V resin composite restorations when 36% H_3PO_4 etching and 36% H_3PO_4 etching followed by deproteinization with 5% NaOCl were used to expose fresh dentin surfaces.

METHODS AND MATERIALS

Microleakage

Ten non-carious human molar teeth stored in saline solution for up to one month at 4°C were selected for this project. After surface debridement with a hand scaling instrument and cleaning with a rubber cup and slurry of pumice, two standardized Class V cavity preparations were prepared in the buccal and lingual surfaces at the cemento-enamel junction. The preparations were made with a 329 carbide bur ISO order nº 329008 (Komet, Kalma SA, 28033 Madrid, Spain) with a high-speed handpiece to a uniform kidney-shaped outline using a template. The preparations measured 5 mm long, 3 mm wide and 2 mm deep, with the gingival margin in dentin or cementum and the occlusal margin in enamel. The occlusal margin was beveled at 45° using a fine grit diamond stone ISO order nº 806314233524012 (Komet, Kalma SA). The width of the bevel was 0.5-1.0 mm. The teeth were randomly assigned to two groups.

After completing the preparations, the bonding system Prime & Bond 2.1 (Dentsply DeTrey, D-78467 Konstanz, Germany) was applied according to the manufacturer's directions in five teeth (Group 1). Enamel and dentin were etched with 36% H_3PO_4 (Conditioner 36, Dentsply DeTrey) for 15 seconds and rinsed for 10 seconds. The dentin surface was then blot-dried. A wet-bonding technique (Kanca, 1992a) was followed, as per Van Meerbeek & others (1998), who stated that a sufficiently moist dentin surface is clinically evidenced by a uniform shiny surface on which water is not pooled. The adhesive Prime&Bond 2.1 was applied in ample

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amounts, left undisturbed for 30 seconds, gently air-thinned to evaporate the acetone and light cured for 20 seconds. A second coat of adhesive was applied and immediately air thinned.

In the other five teeth (Group 2), after applying and rinsing the acid conditioner, the dentin surface was deproteinized with 5% NaOCl for two minutes with constant agitation and rinsed for two minutes with distilled water. The adhesive was then applied as in Group 1.

Prisma TPH resin composite shade A3.5 (Dentsply DeTrey) was inserted in two increments to avoid the problem of "depth of cure" and to decrease polymerization shrinkage. The surface of the composite was light cured for 40 seconds with a Translux EC curing unit (Kulzer GmbH, Bereich Dental, D-6393 Wehrheim, Germany). Curing light output was monitored with a Demetron Curing Radiometer (Model 100, Demetron Research Corporation, 5 Ye Olde Road, Danbury, CT 06810-7377). The restorations were finished to contour with a H135 014 (ISO order) finishing bur (Komet, Kalma SA) with air and water spray in a high-speed handpiece and Sof-Lex Discs (3M Dental Products Division, St Paul, MN 55144-1000); medium, fine and superfine discs were used in sequence in a slow speed handpiece accompanied by air/water spray.

All specimens were stored in tap water at 37°C for one week. Groups were prepared for microleakage evaluation by coating the complete tooth with one application of nail varnish except for 1 mm around restoration margins. The apices of the teeth were sealed with zinc-oxide eugenol cement IRM (Dentsply Caulk, Milford, DE 19963-0359). These specimens were then subjected to 500 temperature cycles (Crim & García-Godoy, 1987). Each cycle consisted of 30 seconds at 6°C and 30 seconds at 60°C. Following thermocycling, the teeth were inverted and placed in a solution of 2% basic fuchsin dye for 24 hours at room temperature. The level of the dye covered the coronal portion of the tooth, preventing leakage through the root apices of the teeth. Each specimen was rinsed with water, lightly pumiced to remove superficial dye and embedded in a phenolic ring with epoxy resin. Each tooth was sectioned longitudinally in a buccolingual direction at three intervals along each restoration with a low-speed water-cooled diamond saw (Accutom Hard Tissue Microtome, Rego&Cia SA, 41007 Sevilla, Spain). The four parts produced from the sectioning were then separated. The cut surfaces corresponding to the most mesial, central and distal portion of the tooth restoration interface were then examined at the occlusal and gingival margins using a stereomicroscope (Model SZ4045TR, Olympus Optical Co, GMBH, D-20097 Hamburg, Germany) at X16 magnification. Since Mixson & others (1991 reported that microleakage may be more extreme at mesial and distal margins of a restoration, these areas were chosen for evaluation. The specimens were randomly examined by two observers who were unaware of the exact nature of the restorative material.

Table 1: *Microleakage Scores*

Microleakage score	Penetration
0	No dye penetration
1	Partial dye penetration along the occlusal or gingival wall
2	Dye penetration along the occlusal or gingival wall, but not including the axial wall
3	Dye penetration to and along the axial wall

The staining along the tooth restoration interface was recorded according to the criteria in Table 1. The worst value (maximum amount of leakage) recorded for each margin was selected for analysis. If conflicts occurred in scoring, consensus was obtained between observers. The occlusal and gingival scores for each group of restorations were compared using the Mann-Whitney U nonparametric statistical test. Combined occlusal and gingival mean scores within each restoration were compared using the Wilcoxon matched pairs signed rank test.

Electron Microscopy

Two specimens of each group were used for analysis by SEM. After the specimens were examined with the stereomicroscope, an individual impression of each interface was taken with an elastomeric material (Aquasil LV, Dentsply Caulk, Milford, DE 19963-0359) and the impressions were poured up in epoxy resin (Epo-thin, Buehler Ltd, Lake Bluff, IL 60044). The specimens were then immersed in 2.5% glutaraldehyde in 0.1 M sodium cacodylate buffer (Electron Microscope Sciences, Fort Washington, PA 19034) (pH 7.4) for 12 hours at 4°C. After fixation the disks were rinsed with 20 mL of 0.2 M sodium cacodylate buffer at pH 7.4 for one hour with three changes, followed by distilled water for one minute. They were then dehydrated in ascending grades of ethanol (25% for 20 minutes, 50% for 20 minutes, 75% for 20 minutes, 95% for 30 minutes and 100% for 60 minutes). After the final ethanol step, the specimens were dried by immersion in hexamethyldisilazane (Electron Microscope Sciences) for 10 minutes, placed on a filter paper inside a covered glass vial and air dried at room temperature. Half of each tooth was embedded in self-curing epoxy resin (Epo-thin, Buheler Ltd) and stored at 37°C for 12 hours. After setting, the epoxy casts were metallurgically polished to high gloss with waterproof silicon carbide papers of decreasing abrasiveness (600, 1200 and 4000 grit) and soft tissue disks with

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Table 2: *Microleakage Scores Obtained for Each Experimental Group*

Scores	Occlusal Cavosurface Margin					Gingival Cavosurface Margin				
	0	1	2	3	T	0	1	2	3	T
H_3PO_4	8	2	-	-	10	-	3	2	5	10
H_3PO_4 + NaOCl	9	-	-	1	10	-	2	3	5	10

No significant differences were obtained between groups, neither at occlusal or gingival margins. Gingival leaked significantly more than occlusal margin in both groups.

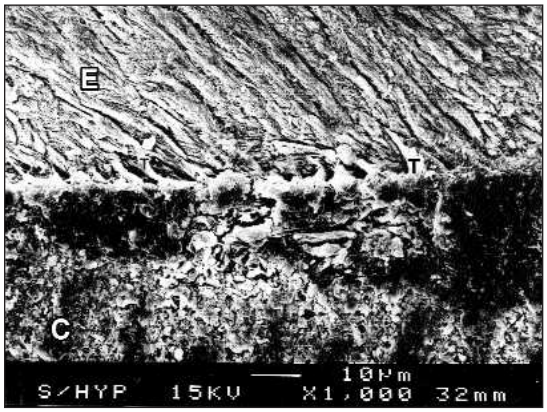

Figure 1. *Enamel-resin interface after etching with 36% H_3PO_4. Note a tight interface with any gap formation. E=Enamel, C=Composite, T=Resin Tag.*

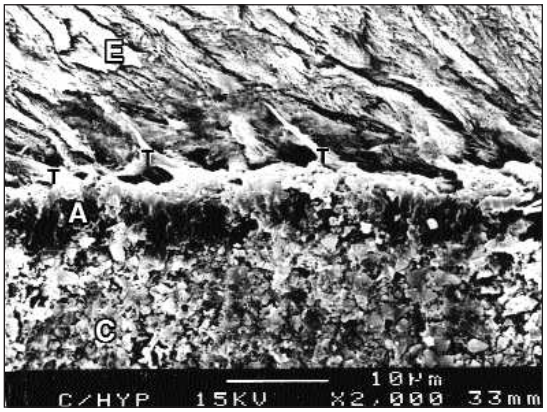

Figure 2. *Enamel-resin interface after etching with 36% H_3PO_4 and deproteinization with 5% NaOCl. Note a tight interface without any gap formation.*
E=Enamel, A=Adhesive, C=Composite, T=Resin Tag.

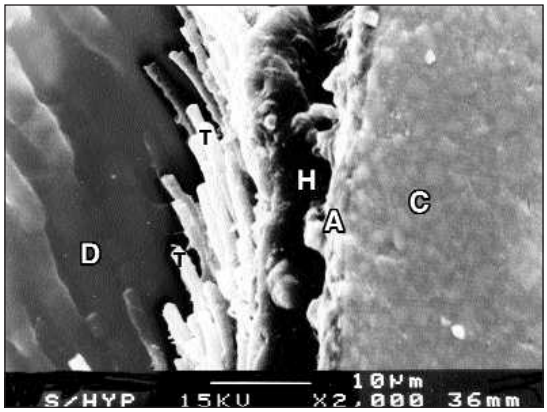

Figure 3. *Axial dentin-resin interface after etching with 36% H_3PO_4.*
D=Residual Dentin, T=Resin Tag, H=Hybrid Layer, A=Adhesive, C=Composite

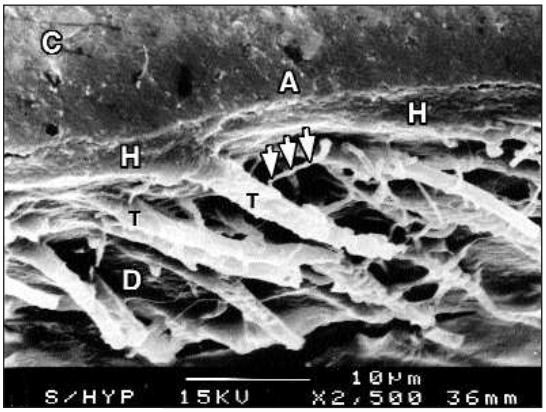

Figure 4. *Cervical dentin-resin interface after etching with 36% H_3PO_4. The arrowheads denote a tubular anastomoses. C=Composite, A=Adhesive, H=Hybrid Layer, T=Resin Tag, D=Residual Dentin.*

increasingly fine diamond suspensions (Buheler Ltd) to a particle size of 1 µm. The top of the epoxy cast was sectioned with an Isomet diamond-saw (Buheler Ltd) to separate the specimen from the epoxy block.

All specimens (embedded in epoxy resin and non-embedded) were immediately ultra-sonicated in 100% ethanol for five minutes, thoroughly dried, demineralized in 6 N HCl for 30 seconds and deproteinized in 1% NaOCl for 10 minutes. They were mounted on aluminum stubs (Ted Pella, Inc, Redding, CA 96049-2477), with carbon cement (Ted Pella, Inc) and colloidal quick-drying silver paint (Ted Pella, Inc). They were then sputter-coated with gold-palladium by means of a Polaron E-5100 sputter-coater (Polaron Equipment Ltd, Watford, WD1 8XG England) at 10 mA for 1.5 minutes and observed under a JSM 6300 (JEOL USA Inc, Peabody, MA 01960) scanning electron microscope at an accelerating voltage of 15 kV and a working distance of 30-36 mm. The epoxy casts were also sputter-coated, observed under the SEM and compared to the actual dentin-resin sections to control for artifact formation.

The morphological appearance of the resin-dentin interface surfaces was compared by screening the entire resin-dentin interface of each specimen.

RESULTS

Microleakage

None of the procedures tested in this study completely eliminated microleakage. Leakage scores are presented in Table 2. On the occlusal wall, the Mann-Whitney U test found no statistical differences between specimens

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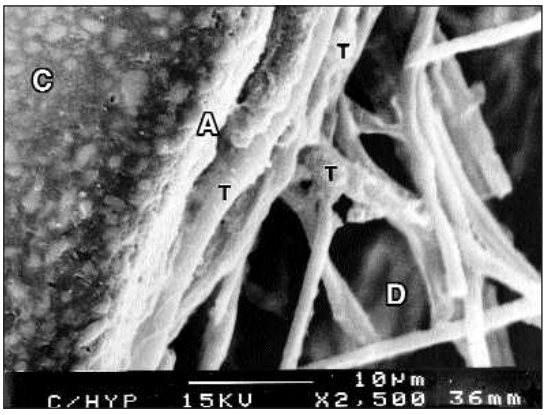

Figure 5. *Axial dentin-resin interface after etching with 36% H_3PO_4 and deproteinization with 5% NaOCl. C=Composite, A=Adhesive, T=Resin Tag, D=Residual Dentin*

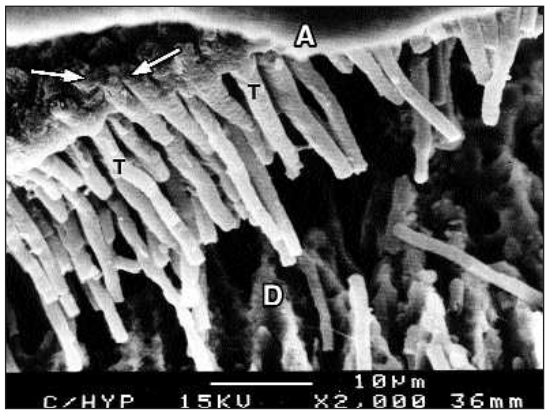

Figure 6. *Cervical dentin-resin interface after etching with 36% H_3PO_4 and deproteinization with 5% NaOCl. Note the formation of a gap. The arrows denote the detachment above the tag necks.*
A=Adhesive, T=Resin Tag, D=Residual Dentin

that had been etched and those etched and deproteinized ($p>0.6264$). Nor was any statistical significance found when gingival microleakage data was evaluated ($p>0.8372$).

When comparing occlusal leakage to gingival leakage in each group, occlusal margins leaked significantly less than gingival walls ($p\leq 0.001$).

Electron Microscopy

SEM findings are summarized with the micrographs in Figures 1 to 6. For specimens that had been etched but not deproteinized, a hybrid layer formed along the entire interface but exhibited an interfacial gap in some areas that represented about half of the total interface length. This gap was consistently present at the axial region closer to the axiogingival line angle. At the gingival interface the gap formed alternated with zones of perfect seal. No gap formed between the adhesive and enamel at the occlusal margin regardless of the protocol used for conditioning prior to applying the adhesive. For specimens in which the formation of the hybrid layer had been prevented, the adhesive contacted directly with the necks of the resin tags, but some areas still showed an interfacial gap equal to about half of the interface length. The pattern observed for specimens in which the hybrid layer was present was also observed for specimens in which the hybrid layer was not formed. All the gaps that were observed on the gingival margins were also observed in the epoxy replicas.

DISCUSSION

A desirable property of dentin bonding systems that remove smear layers, eg, the total-etch dentin bonding systems, is that they seal the resin-dentin interface, thus preventing exposure of the pulp-dentin complex to bacteria and their toxins (Perdigão & others, 1996).

Unfortunately, no restorative procedure evaluated in this investigation completely resisted microleakage at gingival margins of the restoration. Leakage of the resin composite restoration may be attributed to the contraction gap that formed under the restoration from polymerization shrinkage and expansion and contraction of the substrates with temperature changes because the coefficient of thermal expansion of the resin composite is different from that of the dental hard tissues (Bullard, Leinfelder, Russell, 1988). The extent of the curing shrinkage determines creation of marginal gaps if the filling material did not sufficiently adhere to tooth structure, or it could cause cohesive failures in the material (van Dijken, 1996).

The active constituent of Prime & Bond 2.1 is PENTA, an acidic phosphonated monomer. Elastomeric dimethacrylate resins are also included in the formulation. They compensate for polymerization contraction of the resin composite, thereby improving bonding (Saunders & Saunders, 1996). However, these resins may not be sufficiently thick to compensate for the shrinkage stress.

Both groups in this investigation showed higher leakage on gingival than on occlusal margins. Since leakage at the cervical margins of Class V resin-composite restorations may be observed despite the use of bonding systems that create hybrid interfaces; these systems' ability to hybridize cementum must be questioned. Only Tay & others (1995) reported hybrid layer formation in cementum. Cagidiaco & others (1997) concluded that the leakage observed at cervical margins may be related to the absence of dentin tubules in the cervical margin, the relatively low number of tubules in the first 200-300 µm depth of the gingival floor and the mainly organic nature of the dentin substrate. Enamel, when present at the cervical margin, is usually thin, aprismatic and less receptive to bonding. When polymerized, the composite resin shrinks towards the superior bond at the occlusal margin and away from the weaker bond at the gingival margin (Asmussen, 1975).

The minor enamel leakage noted may be due to "enamel crazing." Crim (1993) postulated that the enamel crazing was due to the lack of a bevel at the

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enamel cavosurface margin and the subsequent polymerization shrinkage of the resinous material. In this study, the occlusal margins were beveled and not finished as a butt joint, which may have contributed to the low incidence of enamel leakage.

Enamel leakage, according to this study, was not affected by the use of NaOCl as a deproteinizing agent because bonding of resin composite to enamel was achieved micro-mechanically, and the goal of enamel etching is just to clean the enamel, remove the enamel smear layer and increase microscopic roughness (Retief, 1975). It seemed that an application of 5% sodium hypochlorite for two minutes did not affect the diffusability of the resin into the etched enamel. Low microleakage scores on enamel could also be due to the use of Prime & Bond 2.1 because acetone-solvent systems have been shown to bond just as successfully to dry, etched enamel as to a wet surface (Kanca, 1992b).

In this investigation, similar leakage values were found in acid-treated dentin as in collagen-depleted dentin. The data suggested that the demineralized collagen layer may not contribute to the quality of adhesion when using Prime & Bond 2.1. The permeability of dentin substrates and the ability of monomers to diffuse in these substrates are essential to dentin bonding. Acid etching is not intended to promote wettability because demineralization leads to a hydrophobic surface (Van Meerbeek & others, 1998). However, after acid etching, even assuming a decrease in dentin surface energy by the exposure of collagen fibers, wettability became higher due to an increase in surface roughness (Toledano & others, 1999). Upon etching, the peritubular dentin was demineralized, removed and tubule lumens enlarged. These changes resulted in a much more porous dentin (Kinney & others, 1995). Acid etching may have also produced a collapse of collagen due to the action of the surface tension forces at the air-liquid interface, which would exert a powerful force causing the collagen matrix to flatten (Van Meerbeek & others, 1992). To achieve satisfactory adhesion, this collagen fibril web, deprived of its mineral support following acid treatment, should keep its spongy-like quality, allowing interdiffusion of resin monomers in the subsequent priming and bonding steps (Van Meerbeek & others, 1998). The dentin should not become so dry that collapse of collagen occurs, and it should not become too wet because water limits the penetration and performance of resins. An incomplete resin infiltration within the demineralized intertubular matrix resulted in a weak collagen-rich zone that was susceptible to hydrolysis and microleakage. This region of unprotected collagen fibers may also be susceptible to degradation from acids and enzymes released by bacteria and may be the weak link in achieving durable bonding (Burrow, Satoh & Tagami, 1996; Tanaka & Nakai, 1993). Furthermore, the attachment based on protein structures has been shown to be unstable over time (Gwinnett, 1994a).

Prime & Bond 2.1 contains acetone that could replace water within the pores between the collagen fibers. In this chemical dehydration, the water diffuses from the wet dentin into the acetone, while the acetone diffuses into the demineralized dentin matrix and the primer monomers, dissolved in acetone, also diffuse into the spaces previously occupied by water (Pashley & Carvalho, 1997). Nevertheless, some regions of a complex cavity preparation may suffer from the "overwet phenomenon" resulting in regional variability of dentin bonding (Prati & others, 1991; Cagidiaco & others, 1997). This may also occur wherever there are regions of excessive extrinsic surface moisture, such as line angles or gingival floors.

Using deproteinization processes to remove the superficial de-stabilized collagen layer and subsurface remnants from etched dentin surfaces is proposed (Perdigão & others, 1996). Sodium hypochlorite is a non-specific proteolytic agent that effectively removes organic components at room temperature. The literature shows that NaOCl treatment removes dentin organic components and changes its chemical composition (Sakae, Mishima & Kozawa, 1988) so that it becomes similar to etched enamel (Tanaka & Nakai, 1993). This substrate is also rich in exposed hydroxyapatite crystals (Wakabayashi & others, 1994) and may result in a stable interface over time because it is essentially made of mineral.

After sodium hypochlorite treatment, an increase in wettability was expected because deproteinization results in a hydrophilic surface and the chemical interactions between the resin and the deproteinized dentin are most likely to occur (Attal, Asmussen & Dégrange, 1994; Perdigão, 1995; Toledano & others, 1999). Other authors (Barbosa, Safavi & Spangberg, 1994; Inaba & others, 1995) found that dentin permeability was also enhanced upon removal of organic materials. Wakabayashi & others (1994) and Perdigão & others (1999) describe the dentin surface after treatment with NaOCl for two minutes as having a wider opening of the dentinal tubules and fine irregularities existed on the intertubular dentin, indicating a clear difference in results from those obtained with the phosphoric acid treatment alone. The morphology of the substrate played a prominent role (Cadigiaco & others, 1997), and after deproteinization, dentin became a porous structure with irregularities, allowing good mechanical retention (Vargas, Cobb & Armstrong, 1997).

It seemed that dentin subsurface remnants after deproteinization were able to achieve good resin bonding. Therefore, the qualitative and quantitative role of collagen fibers in optimizing adhesion can be questioned. Gwinnett (1994b) raised doubt concerning

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the quantitative contribution that the collagen made to interfacial bond strength; increasing the thickness of the collagen network did not influence the assembly strength and, furthermore, removal of the collagen with 5% sodium hypochlorite provided similar values to those recorded when the network was present. Gwinnett & others (1996) reported that removal of the collagen exposed by acid conditioning produced a ragged, irregular dentin surface devoid of a hybrid layer after applying the respective adhesive system, although tubules and their lateral branches were completely filled with resin.

Gwinnett (1994a) concluded that it was not necessary to deproteinize dentin when the wet bonding technique was used, which would account for the reduced microleakage differences between both study groups. Prime & Bond 2.1 also contains a phosphoric acid ester, and it is possible that these phosphate terminals could have some kind of interaction to the calcium ions left on dentin surface after collagen removal (Inai & others, 1998). Encapsulation of hydroxyapatite crystallites (Tay, Gwinnett & Wei, 1996) was inferred from the presence of an electron-dense zone adjacent to the unaltered dentin at the base of the hybrid zone following partial demineralization of ultra-thin sections. Kanca & Sandrik (1998) also found similar bond strengths when the dentin was etched, whether or not the loose, demineralized collagen layer was removed. Shear bond strengths were significantly higher when the adhesive (acetone-solved) was applied to a wet surface (etched or etched and deproteinized) than when applied to a dried dentin surface.

Results of this study support previous findings (Gwinnett, 1993; Wakabayashi & others, 1994; Gwinnett & others, 1996) that collagen-rich dentin zones may play no significant role per se in bonding. Some authors report that dentin collagen does not contribute to dentin adhesion and may even interfere with the bonding mechanisms due to the fragile structure of collagen fibers after etching (Gwinnett, 1993; Tanaka & Nakai, 1993; Gwinnett, 1994b; Wakabayashi & others, 1994; Inaba & others, 1995; Burrow & others, 1996; Gwinnett & others, 1996; Vargas & others, 1997).

If a hybrid layer is not necessary to obtain good bonding, it might be possible to perform better bonding between dentin adhesives and collagen-depleted dentin surfaces using improved materials and techniques. If adhesion between dentin minerals and dentin adhesives is obtained, it might be possible to achieve better durability of the hybrid layer (Inai & others, 1998); however, future research is needed.

Although the results obtained from this study cannot be directly related to clinical situations, it provides information regarding the performance of new dentin treatment procedures, but independent long-term clinical data are still required.

CONCLUSIONS

Within the limitations of this *in vitro* study, marginal leakage upon the application of an acetone one-bottle dentin adhesive does not depend on the integrity of the demineralized dentin collagen layer.

Acknowledgments

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Retentive Strength of an Amalgam Bonding Agent: Chemical vs Light vs Dual Curing

MM Winkler • B Rhodes • BK Moore

Clinical Relevance

The light-cured and dual-cured (light and chemical) versions of a bonding agent provided greater retention for an amalgam restoration than did the chemical-cured restoration.

SUMMARY

Dentin bonding agents have been shown to enhance retention of amalgam restorations by mechanical means. Little research is available on which mode of curing may optimize amalgam bonding. This in vitro **study compared the bond strengths exhibited by three variations of a bonding agent, each using a different curing mode, with two earlier versions of amalgam resin liners and cavity varnish. The six test groups of lining agents for amalgam restorations included [C] chemical-cured, [L] light-cured and [D] dual-cured versions of one filled adhesive resin (Clearfil Liner Bond 2V), [LF] Light-cured, Filled resin (Clearfil Liner Bond 2, Kuraray Co.); [LCF] Light- and Chemical-cured, Filled resin Clearfil Liner Bond + Protect Liner, Kuraray Co) and [V] Varnish (Copalite, Cooley & Cooley, Ltd). For each group, 20 Class V cavity preparations were cut in human molars. The preparations were 2.5 mm deep and 3 mm wide at the pulpal floor, with a slightly divergent taper. After treating the preparation with the bonding agent, a 3/4 inch, 18 gauge flat-headed wire nail was seated in the cavity with its head at the pulpal floor of the preparation, and Tytin amalgam (Kerr Corp, Romulus, MI) was condensed into the preparation around the nail. All restorations were stored for 24 hours in distilled water at 37°C, then subjected to 2500 thermal cycles (8°C to 58°C). After one week the samples were tested to failure in tension using an Instron Universal Testing Machine (crosshead speed = 2 mm/min) and peak load (kg) was recorded. Significant differences in retention were found using ANOVA and the Games & Howell post hoc test** ($p=0.05$)**. The mean loads at failure (± SD) were C 13.1 (±2.4), L 21.8 (±6.1), D 26.8 (±7.4), LCF 23.8 (±7.4), LF 21.4 (±3.3) and V 2.0 (±1.8). All dentin-bonding agents exhibited significantly greater retention than the varnish. While the bond strengths of the dual cured (D) and the light-cured (L) liners were not significantly different from one another, both were sig-**

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nificantly higher than the chemically-cured (C) resin liner in terms of retention.

INTRODUCTION

Amalgam bonding agents have been generally beneficial in the restoration of teeth when tested under *in vitro* conditions (Mahler, 1996). The resistance of amalgam restorations bonded with some adhesive resins was similar to the resistance afforded by using pins (Imbery, Burgess & Batzer, 1995) or retentive grooves (Della Bona & Summitt, 1998). In contrast, some bonding agents offered significantly less resistance than pins (Imbery & others, 1995). The concurrent use of pins and an amalgam bonding agent increased the resistance to fracture (Imbery & others, 1995; Burgess, Alvarez & Summitt, 1997) as did the simultaneous use of both undercuts and an amalgam bonding agent (Staninec, 1989). Significant cusp reinforcement occurred when bonding agents were used in placing amalgam restorations (Pilo, Brosh & Chweidan, 1998). Fracture resistance of endodontically-treated molars restored with amalgam increased with the use of an amalgam-bonding agent (Donald, Jeansonne, Gardiner & others, 1997). Similarly, fracture resistance improved for premolars with large MOD preparations (Oliveira, Cochran & Moore, 1996). However, the investigators found that there was still room for improvement of the current bonding procedures, since the most frequent site of failure was at the tooth/restoration interface.

Several studies of bonded amalgam restorations have found a reduction in microleakage at the cavosurface margin (Staninec & Holt, 1988; Charlton, Moore & Swartz, 1992; Edgren & Denehy, 1992; Saiku, St Germain & Meiers, 1993; Ben-Amar, Liberman, Rothkoff & others, 1994). Gaps generally formed between the bonding agent and the amalgam (Saiku & others, 1993). While these laboratory data suggest significant improvement in the marginal seal compared with varnish, clinical data suggests that there is still need for improvement. In a clinical study, the claim of elimination of postoperative sensitivity to cold could not be substantiated (Browning, Johnson & Gregory, 1997).

The stability of the amalgam bond is controversial. A six-month *in vitro* study found that the shear bond strength significantly deteriorated as time of immersion increased for the bonding agents (Pilo, Brosh, Shapinko & others, 1996), while a 48-week *in vitro* study found no significant effect on these same two bonding agents (Hasegawa & Retief, 1996). A study of fracture resistance of MOD amalgams found no difference after samples were aged for 67 days (Santos & Meiers, 1994). In one study cyclic loading significantly reduced the shear bond strength (McComb, Brown & Forman, 1995). Another study employing cyclic loading revealed that while gaps formed at the margins after loading, they were relatively harmless, as they typically occurred between the amalgam and the liner and not between the bonding agent and the tooth (Tarim, Suzuki & Cox, 1996). The bonded amalgams also tended to have smaller gaps than the non-bonded amalgams.

The study investigated whether one variable, curing mode, affected the magnitude of retentive strength of an amalgam-bonding agent. Research on which mode of curing may optimize amalgam bonding is minimal. This, in part, is due to the fact that most bonding agents are currently light cured because they possess the luxury of extended working time. Therefore, less opportunity is available to investigate this potential effect without other confounding variables present. In a previous study that evaluated whether curing modality had an effect on retention of amalgam bonding agents, there was no clear evidence of its effect due to the confounding of other variables, such as differences in chemistries that were unrelated to the mode of polymerization (Winkler, Moore, Allen & others, 1997). This study more specifically focused on this effect by utilizing different versions of one bonding agent which could be cured by any of three activation methods, light, chemical and a combination of light and chemical.

METHODS AND MATERIALS

Six amalgam liners were evaluated for their enhanced retention of Class V amalgam restorations. The six test groups of lining agents for amalgam restorations included [C] chemical-cured, [L] light-cured and [D] dual-cured versions of one filled adhesive resin (Clearfil Liner Bond 2V, Kuraray Co, Ltd, Osaka 530, Japan), [LF] Light-cured, Filled resin (Clearfil Liner Bond 2, Kuraray Co, Ltd); [LCF] Light- and Chemical-cured, Filled resin Clearfil Liner Bond + Protect Liner, Kuraray Co, Ltd) and [V] Varnish (Copalite, Cooley & Cooley Ltd, Houston, TX, USA). The cavity varnish was added as a negative control, and Liner Bond and Liner Bond 2 were used as positive controls for this study.

C, L and D are versions of the same basic product. They only differ with regard to curing modality afforded by the presence of benzoyl peroxide in D and C and the employment of a curing light for L and D.

As a group, the five resin-based amalgam liners, C, L, D, LF and LCF are relatively similar in terms of the chemistry of their adhesive resins. Each contains MDP (10-Methacryloyloxydecyl dihydrogen phosphate) monomer and HEMA (2-Hydroxyethyl methacrylate) (Kuraray Co, 1992; Kuraray Co, 1995; Kuraray Co, 1998). Also, each has filler in a component of the bonding system. The LCF has a micro-filler, prepolymerized particles plus colloidal silica in the overlying resin liner, while LF, C, L and D have only colloidal silica in the adhesive resin.

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Greater differences exist in the etchants and primers (Kuraray Co, 1992; Kuraray Co, 1995; Kuraray Co, 1998). For LCF, the primary etchant is a citric acid solution. The etchants for the other resin-based liners are included within the primers. MDP is utilized as the etching component in the self-etching primers of C, L and D. Phenyl-P is thought to function in LF both as an etchant and as a monomer that can be polymerized. An adhesive monomer, 5-NMSA (salicylic acid derivative monomer) is also included with the primer of LCF and LF and may potentially bind to collagen.

Retention

For each group, 20 Class V cavity preparations were cut on the facial, lingual, or proximal surfaces of human molars. To minimize variation between and within preparations, they were cut with water spray using a high-speed dental handpiece attached to a small machine lathe with a water spray. The preparations (Figure 1) were 2.5 mm deep and 3 mm wide at the pulpal floor with a slightly divergent taper (about 5% for one wall or 10% total taper). All margins were in enamel. Prior to restoration placement, the prepared teeth were stored in distilled water. A tapered fissure-carbide bur with no cross-cuts (#171, Brasseler USA Inc, Savannah, GA, 31419) was used to prepare the final surface finish on the cavity walls.

Immediately prior to restoration, the teeth were rinsed with a water spray for 20 seconds. With one exception, the adhesive resins were prepared and applied to the cavity walls according to the manufacturer's instructions. The only exception was for LCF (Liner Bond with Protect Liner) in which the Photo Bond adhesive resin was not light cured prior to placement of the Protect Liner. The Protect Liner was light cured prior to amalgam condensation. It should be noted that for amalgam bonding with Clearfil Liner Bond 2V, the manufacturer's instructions state that the resin should be applied using a dual cure (D).

A 3/4 inch 18-gauge flat-headed wire nail was placed into the cavity with the head at the pulpal floor of the preparation. At least one day prior to their use, all nail heads were coated with cavity varnish in order to prevent bonding between the nail and the floor of the preparation. The diameter of the head of the nail closely matched the diameter of the preparation at the pulpal floor so that bonding between amalgam and tooth was limited to the tapered walls of the preparation.

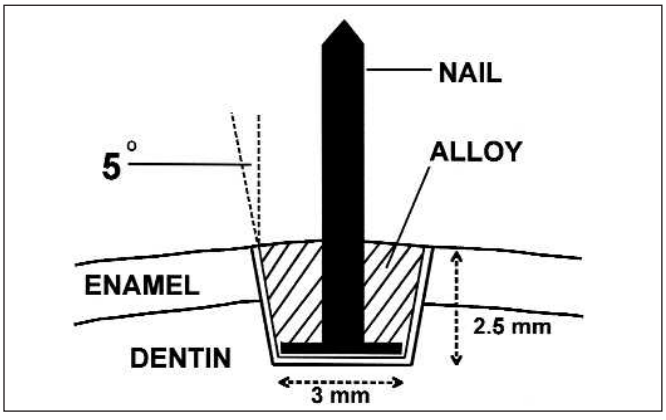

Figure 1. *Diagram of cross section of amalgam bonding sample.*

A spherical silver amalgam (Tytin, lot #41159 and 51066, Kerr Manufacturing Co, Romulus, MI 48174) was triturated for eight seconds at the M2 setting of a mechanical amalgamator (Vari-Mix II, L D Caulk Co, Division of Dentsply, Milford, DE 19963) and condensed into the preparation around the nail. After carving the amalgam surface flush with the cavosurface margin, the restored tooth was stored in distilled water at 37°C. At least one day later, all samples were subjected to 2500 thermal cycles (8°C to 58°C) with a dwell time of 30 seconds. One week after placement of the amalgam restoration, specimens were tested in tension using an Instron Universal Testing Machine (Model 1123, Instron Corp, Canton, MA 02021) modified with an upgrade (Sintech ReNew, MTS Systems, Eden Prairie, MN, 55344) at a crosshead speed of 2 mm/min. Connected to the upper grip of the testing machine was a metal swivel-assembly holding the embedded tooth and connected to the lower grip was a drill chuck fastened to the nail protruding from the amalgam. Samples were tested to failure and peak load (kg) was recorded. Any fracture of tooth structure was noted, and the mode of failure was determined by examination of the retrieved amalgam restorations using an optical stereomicroscope at a magnification of 40X.

The peak loads at failure for the six groups were analyzed using a one-way ANOVA (p=0.05). Since the data failed the test for equal variance, a Games & Howell post hoc test was used for specific comparison tests. Data was also submitted to Weibull analysis (Johnson, 1964). The characteristic life, the data value below which lie 63.2% of the data values, and the shape factor, an indication of variation of the data values, were calculated. Data points were plotted on a Weibull distribution grid using custom computer software (Winkler, 1991).

Confocal Microscopy

Cross sections of bonded amalgam samples were examined using a confocal microscope. Final magnification of the images was about 300X. The sections were cut in a bucco-lingual direction with a high-speed (approximately 10,000 rpm) diamond saw (Gillings-Hamco, Rochester NY, 14601) using a 5-inch, 0.014 inches thick regular concentration diamond saw blade (part #801-135, Leco Corporation, St Joseph, MI, 49085) with water spray. The cut surfaces were finished using 2000 grit silicon carbide paper and then treated with 32% phosphoric acid for 10 seconds. After rinsing with water

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Table 1: *Mean Peak Load at Failure*

Amalgam Liner	Mean Peak Load at Failure (standard deviation) kilograms
D (Clearfil Liner Bond 2V)	26.8 (7.4)
LCF (Liner Bond)	23.8 (7.4)
L (Clearfil Liner Bond 2V)	21.8 (6.1)
LF (Liner Bond 2)	21.4 (3.3)
C (Clearfil Liner Bond 2V)	13.1 (2.4)
V (Copalite)	2.0 (1.8)

Sample Size = 20
**p=0.05, vertical line connects groups with no significant differences

Table 2: *Weibull Pararneters for Peak Load at Failure*

Amalgam Liner	Weibull**	
	Characteristic Life (kg)	Shape Factor (kg)
D (Clearfil Liner Bond 2V)	29.6	3.8
LCF (Liner Bond)	26.4	3.5
L (Clearfil Liner Bond 2V)	24.0	3 9
LF (Liner Bond 2)	22.7	7.2
C (Clearfil Liner Bond 2V)	14.1	6.0
V (Copalite)	2.1	1.2

Sample Size = 20
** Weibull Distribution Pararneters: Characteristic Life is the load value below which 63.2% of the samples have failed. Shape Factor is a load value that describes the variation of the sample distribution. Low shape values are associated with large variation and a shallow slope of the best fit line to sample data when the data are plotted on Weibull paper. In contrast, high shape values are associated with small variation and a steep slope for the best fit line.

and air drying, the samples were mounted on glass slides for viewing under the confocal microscope (Noran Odyssey, Noran Instruments, Middleton, WI 53562). The microscope was operated in the reflected mode using an argon laser light source with a wavelength of 488 nm. Images were obtained by capturing and averaging video frames using computer software (Image I Image Analysis software version 4.14c, Universal Imaging, West Chester, PA 19380).

RESULTS

Retention

The mean peak loads at failure (kg) for both retention tests are listed in Table 1. The multiple comparison tests reveal that there were no significant differences among D, LCF, L and LF. These four agents exhibited significantly higher peak loads at failure than C. Varnish (V) was significantly less retentive than C.

Weibull parameters (Table 2) were determined using maximum likelihood methods. Plots of the six test groups according to the Weibull distribution are shown in Figure 2. Differences among the top four liners are minimal. As indicated by the steeper slopes of the best-fit lines to the data for the resin-based liners, there is less variation in their retentive values than in those for the cavity varnish.

Examination of the failed samples revealed that the fracture mode was generally adhesive. The resin liners

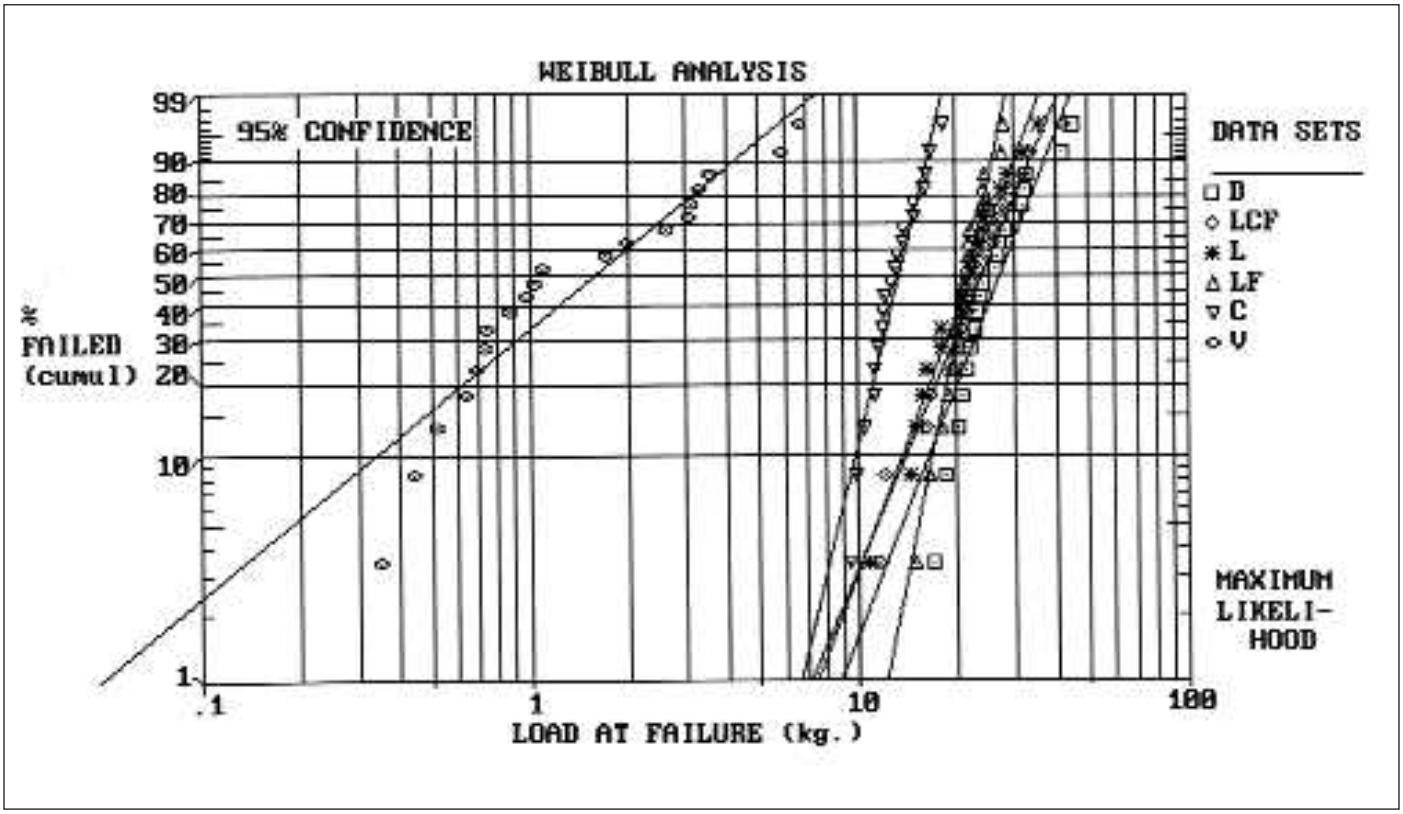

Figure 2. *Peak loads at failure plotted according to Weibull analysis.*

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Figure 3. *Confocal photomicrographs of amalgam/dentin interface. Note that amalgam is on the left and the dentin is on the right in each photomicrograph. The length of the marker is 50 micrometers.*

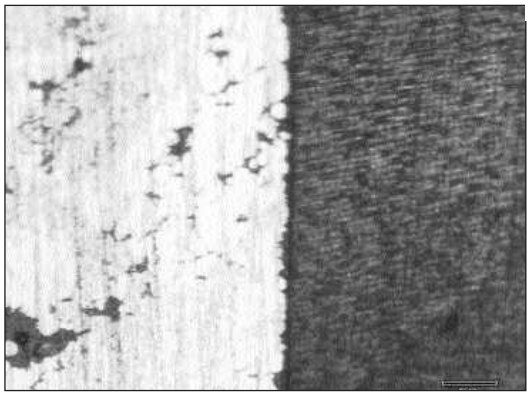

Figure 3A. *Liner C (Clearfil Liner Bond 2V), chemical activation.*

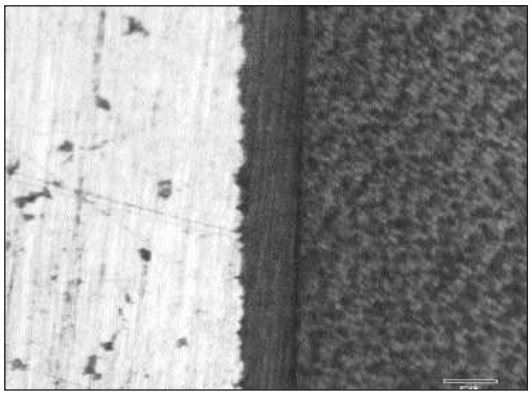

Figure 3B. *Liner D (Clearfil Liner Bond 2V), dual activation.*

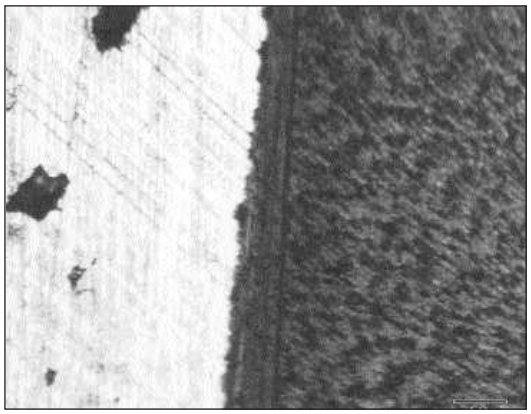

Figure 3C. Liner L (Clearfil Liner Bond 2V), light activation.

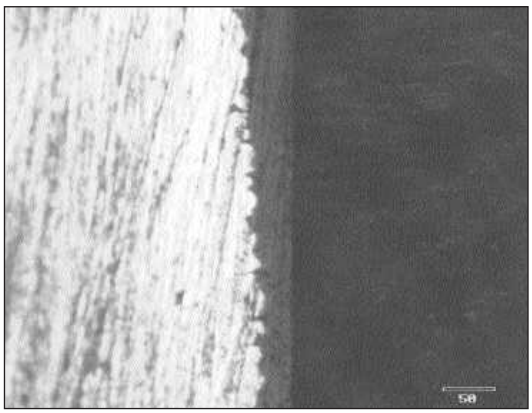

Figure 3D. Liner LCF (Liner Bond), dual activation.

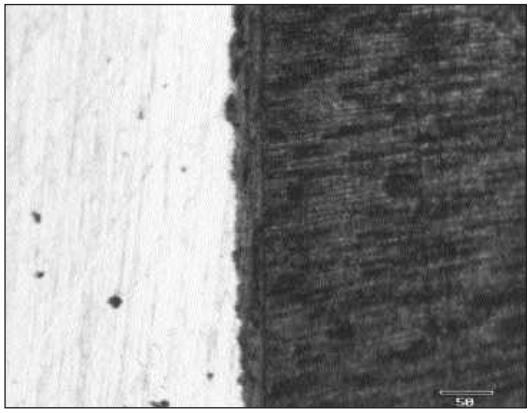

Figure 3E. Liner LF (Liner Bond 2}, light activation.

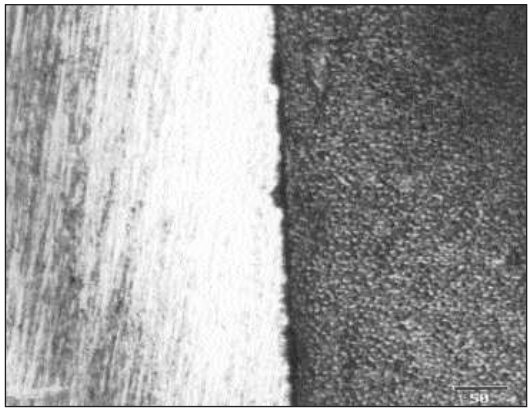

Figure 3F. Liner V (Copalite).

generally remained on the tooth structure with little left on the amalgam. When cohesive failure occurred in tooth structure, it was usually confined to less than 25% of the preparation walls. Among the resin liners, fracture occurred in tooth structure in approximately 50% of the samples and tooth structure remained attached to the amalgam after failure in 5% to 30% of the samples. The cavity varnish (V) was found on both amalgam and tooth structure.

Confocal Microscopy

The confocal photomicrographs (Figure 3) of cross sections of the bonded interface reveal the relative thickness and uniformity of the amalgam liners. The mean thicknesses (calculated from five locations along the interface on these photomicrographs) of the liners are 8 µm for V and 7 µm for C, the chemical-cured resin. The light-cured liners, LF and L, present with thicknesses of 26 µm and 42 µm, respectively, while the light- and chemical-cured liners, LCF and D, exhibit thicknesses of 39 µm and 55 µm, respectively. Islands of bonding resin, especially for the chemical-cured material C, are visible within the amalgam.

Discussion

For the amalgam bonding agents in this study, the retentive strength of the bonded restoration depended on the mode of curing used in activating the polymerization reaction of the bonding agent. The retention values were higher for the dual-cured bonding agent (D) and the primarily light-cured liners (LCF, L and LF) and lower for the chemically-cured liner (C). Note that LCF has some capacity for chemical curing and this added curing modality may help its retentive

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strength. The cavity varnish exhibited very low values for retention. As in a previous study (Winkler & others, 1997), the light-cured materials, including those that were dual-cured, performed better than the chemical-cured liners. This trend is somewhat surprising. For chemical-cured liners with a more slowly hardening bonding agent, it would be expected that the amalgam would mix with the liner, producing interlocking projections for mechanical retention. Less mixing of the amalgam and liner would seemingly occur with the light-cured liners and thus, provide less mechanical retention. With no significant chemical adhesion between the amalgam and the liner, mechanical retention is the predominant means of retention for these adhesive liners. For all resin bonding agents, residual resin liner was usually found on the dentin and enamel walls of preparations after testing to failure and little, if any resin remained on the amalgam. Thus the greatest potential for enhancing the amalgam bond appears to be by improving the bond between the amalgam and the bonding agent.

Previously, differences in liner thickness helped explain differences in retention for some of these same bonding agents (Winkler & others, 1997). Another study (Ramos & Perdigão, 1997) had similar findings for other amalgam bonding agents. The liners presenting the thickest interfaces provided the greatest retention. The cured interfaces of the light-cured materials were relatively thick, while those of the chemical-cured liner were relatively thin. A scanning electron examination of the interface showed that the surface of the light-cured liner was deformed during condensation so that the alloy particles were partially embedded in the resin liner. The softness of the air-inhibited layer is probably most responsible for this effect. Since few, if any, mechanical undercuts were observed within the resin interface, the resulting bonding may not resist tensile forces as well as shear forces. The partial incorporation of the particles within the resin certainly increases resistance to shear forces. In addition, the film thickness of bonding agents is heavily dependent on the operator or placement technique (Temple-Smithson, Causton & Marshal, 1992).

Filled bonding agents have been shown to provide higher bond strengths than unfilled bonding agents (Bagley, Wakefield & Robbins, 1994; Kawakami, Staninec, Imazato & others, 1994). All of the resin-bonding agents were filled in this study, but the type of filler made no significant difference in the retentive strength. The retentive strength of the micro-filled bonding agent, LCF, which contains prepolymerized particles plus colloidal silica, was not significantly different from the strengths of bonding agents, LF, D and L, which contain only colloidal silica.

The choice of amalgam alloy can also affect the bond strength. One study suggests that retentive strengths are improved if a spherical amalgam, instead of an admixed amalgam, is used in conjunction with an amalgam bonding agent (Diefenderfer & Reinhardt, 1997). The investigators speculate that this finding may have been caused by differences in the chemical components of the two amalgam alloys or because the more slowly-setting admixed alloy was more affected by removal of the mold used during condensation of the amalgam than the sperhical alloy.

Future research should focus on evaluating the potential role of curing mode on other brands of bonding agents with the hope of increasing their retentive strength. Another potential avenue for investigation is the effect of the bonding agent's viscosity during amalgam condensation on final retentive strength, since it probably influences the resulting liner thickness which has been found to affect retentive strength.

CONCLUSIONS

1. The resin-based amalgam liners (D, L, LCF and LF), which depended mainly on light for activation of polymerization, were not significantly different from one another but displayed significantly greater retention than the liner that was only chemically-cured.
2. All five resin-based amalgam liners exhibited greater retention than the cavity varnish.
3. Failures were generally adhesive, with most of the residual liner remaining on tooth structure.

Acknowledgments

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Evaluation of Dental Adhesive Systems with Amalgam and Resin Composite Restorations: Comparison of Microleakage and Bond Strength Results

AL Neme • DB Evans • BB Maxson

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Clinical Relevance

The use of an adhesive significantly influenced bond strength and the extent of microleakage in both amalgam and resin composite restorations.

SUMMARY

A variety of laboratory tests have been developed to assist in predicting the clinical performance of dental restorative materials. Additionally, more than one methodology is in use for many types of tests performed in vitro**. This project assessed and compared results derived from two specific laboratory testing methods, one for bond strength and one for microleakage. Seven multi-purpose dental adhesives were tested with the two methodologies in both amalgam and resin composite restorations. Bond strength was determined with a punch-out method in sections of human molar dentin. Microleakage was analyzed with a digital imaging system (Image-Pro Plus, Version 1.3) to determine the extent of dye penetration in Class V preparations centered at the CEJ on both the buccal and lingual surfaces of human molar teeth. There were 32 treatment groups (n=10); seven experimental (dental adhesives) and one control (copal varnish, 37% phosphoric acid) followed by restoration with either amalgam or resin composite. Specimens were thermocycled 500 times in 5° and 55°C water with a one-minute dwell time. Bond strength and microleakage values were determined for each group. ANOVA and Student-Newman-Keuls tests demonstrated an interaction between restorative material and adhesive system with a significant difference among adhesives ($p<0.05$). Using a multi-purpose adhesive system resulted in both a statistically significant increase in bond strength and a statistically significant decrease in extent of microleakage ($p<0.05$). The effect of the adhesive upon both microleakage and bond strength was greater in the resin composite restorations than in the amalgam restorations. Bond strength testing was more discrimi-**

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nating than microleakage evaluation in identifying differences among materials.

INTRODUCTION

During the development and evolution of enamel and dentin bonding systems, methods for testing *in vitro* have been used for screening materials prior to clinical use. According to Pagliarini & others (1996), enamel and dentin adhesives were developed for two purposes: (1) to increase the retention of a restoration, and (2) to reduce the marginal gap at the tooth-to-restoration interface. Bond strength testing and microleakage evaluations are two laboratory methodologies designed to predict the clinical efficacy of an adhesive material relative to these two parameters. Unfortunately, multiple methodologies for these tests interfere with comparison of results among laboratories.

Data from bond strength testing is frequently used to predict the adhesive potential of a material. Pashley & others (1995) reviewed the methodology for bond strength testing and commented on the many improvements over the last 40 years. Although there have been attempts to standardize bond-testing methodology, differences in the bonding substrate, storage conditions for tooth specimens and cavity preparation introduce confounding variables for comparison of data (Rueggeberg, 1991). DeHoff & others (1995) state that most dental researchers use tensile and shear tests to predict the effects of technique and material variables on clinical performance of bonding systems, though there is no evidence of clinical relevance.

Tests designed to measure shear bond strength include the pull shear test and the push shear test, the planar interface shear test, the conical interface shear test and the lap shear test. The most commonly recorded bond strength methodology is the planar interface shear bond test. For this test, a rod of resin composite is polymerized to a dentin surface. Finger (1988) expresses concern about this method of evaluation since the bonding interface is only moderately loaded by polymerization contraction stresses parallel to the flat dentin surface, while shrinkage in a perpendicular direction can occur almost freely and without generation of stresses at the bonding site. These conditions do not compare to those typically found at the margin of a dental restoration. Ritter (1995) argues that for a test to accurately reflect the variability and time-dependency of a product in service, the selected test sample and mode of loading should closely simulate clinical conditions.

Smith & Cooper (1971) describe a punch-out shear test in which a cylindrical specimen of material is pushed through a substrate. Mahler & Nelson (1994) describe a push-out method to measure the force required to remove simulated Class I restorations from cavity molds. This type of test is considered useful for comparing materials where shear forces are present, as at the margins of dental restorations. The unique three-dimensional specimen design of the punch-out shear test may take a variety of stresses into consideration that better simulate the bonded dental restoration model than the flat-bonded specimen in the planar interface shear test. However, frictional forces between restorative material and substrate, and the requirement for parallelism of the preparation walls, are two perplexing variables associated with this method.

It is well recognized that published bond strength data demonstrate much variability in mean values with large standard deviations independent of the test method used. Van Noort & others (1991) have suggested that standards are needed to directly compare data from different testing centers and that these standards should meet the following requirements; proper definition of what is being measured, appropriate method of sample preparation and uniform test design. Until this is accomplished, it could be argued that bond strength data should be reported, not as numerical values, but as ranked data associated with the mode of failure of the specimens.

Review of the literature also demonstrates much variation in methodology for the evaluation of microleakage (Retief, 1991). Söderholm (1991) questioned the relevance of microleakage testing to evaluate dentin adhesion since the effect of microleakage on the survival of the dentin bond *in vivo* is unknown. It has been suggested that the bond between tooth and adhesive material could persist in spite of minimal leakage. However, bond strength tests alone may not adequately address issues more directly related to microleakage, such as secondary caries, pulpal reactions and marginal stain.

If both bond strength and microleakage tests are needed to best predict the clinical behavior of an adhesive dental material, some correlation of data may be expected between the two methods since both methodologies are intended to evaluate related parameters. In fact, such relationships have been reported. Komatsu & Finger (1986) found that a shear bond strength of approximately 20 MPa was required to prevent marginal contraction gaps in butt-joint dentin cavities 15 minutes after polymerization. Later, Retief, Mandras & Russell (1994) compared shear bond strength and quantitative microleakage. Their results suggest that a shear bond strength of 21 MPa may nearly eliminate microleakage. However, studies comparing results from both testing methodologies are rare.

For this study, seven adhesive materials were placed in conjunction with both amalgam and resin composite. All seven materials plus a control were evaluated *in vitro* for both bond strength and microleakage. The same materials were used with both methodologies and manipulated by a single operator according to manu-

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Table 1: *List of Adhesive Systems, Restorative Materials and Their Manufacturers*

Material	Manufacturer
Adhesive Systems	
Amalgambond Plus	Parkell, Farmington, NY 11735
Clearfil Liner Bond 2	J Morita, Tustin, CA 92780
Copalite (Control)	Cooley and Cooley Ltd, Houston, TX 77041
One-Step Universal/Resinomer	Bisco Dental Products, Schaumburg, IL 60193
OptiBond FL	Kerr USA, Orange, CA 92867
Prime and Bond/Advance Hybrid Ionomer Cement	Dentsply/Caulk, Milford, DE 19963-0359
Scotchbond Multipurpose Plus	3M Dental Products, St Paul, MN 55144
Tenure Quik	DenMat, Santa Maria, CA 93456
Amalgam	
Tytin	Kerr USA, Romulus, MI 48174
Composite	
Herculite XRV Resin composite	Kerr USA, Orange, CA, MI 92867

Table 2: *Experimental Groups*

Group	Restorative Material	n	Treatment	Adhesive
1	Composite	10	7% A, 10% B	Amalgambond Plus
2	Composite	10	37% C	Clearfil Liner Bond 2
3	Composite	10	32% C	One-Step Universal
4	Composite	10	37.5% C	OptiBond FL
5	Composite	10	37% C	Prime and Bond
6	Composite	10	35% C	Scotchbond Multipurpose Plus
7	Composite	10	37% C	Tenure Quik
8	Composite	10	37% C	control (none)
9	Amalgam	10	7% A, 10% B, HSP	Amalgambond Plus
10	Amalgam	10	37% C	Clearfil Liner Bond 2
11	Amalgam	10	32% C, Resinomer	One-Step Universal
12	Amalgam	10	37.5% C	OptiBond FL
13	Amalgam	10	37% C, Advance	Prime and Bond
14	Amalgam	10	35% C	Scotchbond Multipurpose Plus
15	Amalgam	10	37% C	Tenure Quik
16	Amalgam	10	copal varnish	control (none)

A= Ferric chloride
B= Citric acid
C= Phosphoric acid

facturer's suggestions. This investigation compared the results from both test methodologies to determine if a relationship between the two sets of data could be identified.

METHODS AND MATERIALS

In this investigation, the bond strength and extent of microleakage of various dentin adhesive systems were measured. The adhesive systems and restorative materials used in this study are listed in Table 1. Human molar teeth stored in 0.2% sodium azide solution were assigned at random, 10 for each group, to 16 groups for bond strength testing and eight groups for microleakage evaluation. Each tooth assigned for microleakage evaluation had both composite and amalgam restorations placed on a single tooth. All products were manipulated according to manufacturer's directions. For each of the two tests performed, there were 16 experimental groups (Table 2).

Sample Preparation: Bond Strength

One-hundred and sixty teeth were invested in clear autopolymerizing resin (Orthodontic Resin, Dentsply/Caulk Co, Milford, DE 19963) with the apices downward within a section of one-inch diameter polyvinylchloride pipe. The samples were wet-ground with 60-grit silicon carbide sandpaper on both the occlusal and apical aspects until a cross section of tooth approximately 3.0 mm in thickness remained (Figure 1). Specimens were then stored in room temperature tap water (37 ± 2°C) for 24 hours. A 3.18 mm (1/8 inch) diameter cylindrical cavity was prepared in the dentin perpendicular to the section plane. The cavity was prepared with a solid carbide brad-point drill cooled with a constant stream of water in a drilling and milling machine (Model RF-20/25, Lincoln Corp, Taiwan). To assure parallelism of the cavity walls, a jig was used to position and support the dentin specimens during the drilling procedure. The samples were then rinsed of debris in tap water and stored in room temperature distilled water for another 24 hours. Cavity surfaces were prepared with each adhesive system according to manufacturers' suggestions. For the composite restoration control group, the dentin was etched with 37.5% phosphoric acid (Kerr Gel Etchant, Kerr USA, Orange, CA 92867) for 15 seconds, rinsed for 15 seconds, then air dried for two seconds. For the amalgam restoration control group, the dentin was rinsed for 15 seconds, air dried for two seconds, swabbed with two coats of copal varnish and allowed to air dry. Cavities were filled with either amalgam or resin composite. The amalgam was triturated in a Vari-Mix III (Dentsply/Caulk, Milford DE 19963) amalgamator for 10 seconds at medium speed. The amalgam was condensed with hand instruments, carved back to minimize flash and allowed to set for 15 minutes. Resin composite was injected into one end of the cylindrical dentin cavity from unit-dose capsules placed in a syringe (Centrix, Centrix Inc, Shelton, CT 06484), while the opposing open end of the cavity was

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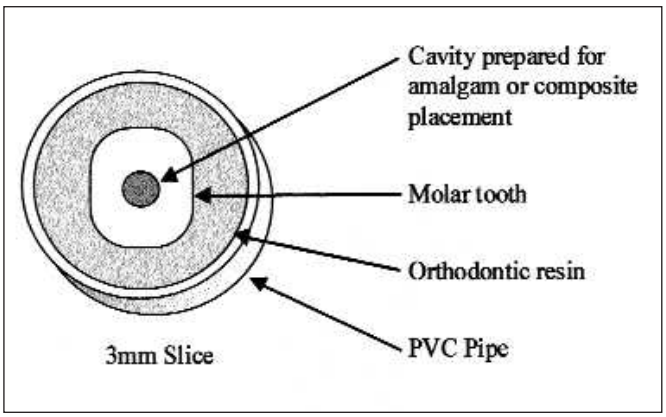

Figure 1. *Bond Strength Sample*

occluded by a glass slide. The resin composite was polymerized for 40 seconds with an Optilux light unit (Model #VLC 401, Kerr Demetron, Danbury, CT 06810) directed from each end of the 3.0 mm preparation without glass slide in place. The light was tested with a radiometer (Cure Rite Visible Light Curing Meter, Model #8000, EFOS Inc, Williamsville, NY 14221) to verify intensity prior to the polymerization of each treatment group. All restorative procedures were done by a single operator.

Sample Preparation: Microleakage

Eighty teeth were cleaned with a rubber cup using a slurry of flour of pumice and water. A single operator prepared Class V cavities on both the lingual and buccal surfaces of each tooth using a high-speed handpiece with water spray and a #170 carbide bur. The preparations were 2 mm deep, centered on the CEJ and measured 3 mm by 3 mm. Lingual cavities were left as prepared for subsequent placement of amalgam. Using a #7902 bur, a 45° bevel was placed at the enamel cavosurface margin of the buccal cavities to prepare for placement of resin composite. All teeth were randomly assigned to eight treatment groups (one of seven adhesive systems or the control group). Each cavity surface was prepared and restorative material placed according to manufacturer's suggestions. Control groups were treated as previously described prior to restorative material placement. Resin composite was placed in 2-mm increments and polymerized for 40 seconds. Composite restorations were finished flush with the tooth surface with the Sof-Lex (3M Dental, St Paul, MN 55144) finishing disk system. Amalgam restorations were overfilled, burnished and carved to proper anatomical contour.

Sample Storage

All specimens were stored in distilled water at 37 ± 2°C for a minimum of 24 hours after restoration and prior to testing. After four hours of storage, bond strength samples were removed from storage, lightly wet-ground with 320-grit silicon carbide paper to eliminate flash material from the restorations, rinsed and returned to storage for the remaining 24 hours. Samples were thermocycled (Model CHCB/2050A, Standard Environmental Systems Inc, Totowa, NJ 07510) 500 times between two waterbaths of 5° and 55°C with a one-minute dwell time in each bath. Following thermocycling, the specimens were stored in distilled water for 72 hours at room temperature before testing.

Bond Strength Testing

Prior to shear stress application, sample thickness was measured with a micrometer caliper (LS Starrett Co, Athol, MA 01331) to allow later calculation of dentin wall surface area. All samples were mounted in a metal jig that centered the restorations over a 4.0-mm hole with the remaining tooth structure supported by the metal sample holder. The specimens were subjected to shear stress using a Zwick Materials Testing Machine (Zwick of America Inc, East Windsor, CT 06088). A 2.78 mm diameter rod at a crosshead speed of 0.5 mm/minute delivered the shearing force perpendicular to the flat tooth surface, punching out the restorations from the prepared bonding sites. Shear bond strengths were calculated and recorded in mega Pascal units (MPa). Following restoration removal, all dentin specimens were sectioned longitudinally in a buccal-lingual direction with an Isomet (Buehler Ltd, Lake Bluff, IL 60044) slow-speed, water-cooled diamond saw. The dentin-to-adhesive interface was then examined with a stereobinocular microscope at 64X to evaluate the mode of failure (adhesive or cohesive). Average bond strengths were determined for each restorative material and adhesive system combination. Significant differences were examined by two-factor Analysis of Variance (ANOVA) and Student-Newman-Keuls at α=0.05.

Microleakage

Following thermocycling, each tooth was coated with fingernail polish to within 1 mm of the restoration margins. Teeth were then placed in a solution of 0.5% basic fuschin dye for four hours at 37 ± 2°C. Following dye exposure, the teeth were rinsed with distilled water and invested with the apices downward in clear autopolymerizing resin (Orthodontic Resin, Dentsply/Caulk Co, Milford, DE 19963) within a one-inch diameter polyvinylchloride pipe. The pipe segments with embedded teeth were sectioned with an Isomet (Buehler Ltd, Lake Bluff, IL 60044) slow-speed, water-cooled diamond saw through the center of both restorations. Dye penetration was measured at both the occlusal and cervical aspects of all restorations using digital imaging (Image-Pro Plus, Version 1.3). Percent of occlusal, cervical and total microleakage was calculated for all restorations. Significant differences were examined by two-factor Analysis of Variance (ANOVA) and Student-Newman-Keuls at α=0.05.

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Table 3: *Bond Strengths*

Adhesive	Amalgam Bond Strength in MPa (SD)	Adhesive	Composite Bond Strength in MPa (SD)
Copalite (Control)	8.3 (3.4)	Acid Etch (Control)	4.1 (3.9)
Tenure Quik	11.0 (3.7)	Tenure Quik	8.2 (2.9)
One-Step/Resinomer	16.6 (4.2)	Scotchbond MP Plus	15.4 (1.7)
Prime and Bond/Advance	18.9 (2.6)	Amalgambond	16.2 (4.0)
Scotchbond MP Plus	22.3 (4.8)	Prime and Bond	19.7 (5.5)
Clearfil LB2	24.5 (4.8)	OptiBond FL	21.9 (6.1)
Amalgambond/HSP	27.0 (5.0)	One-Step Universal	22.5 (2.0)
OptiBond FL	33.0 (5.1)	Clearfil LB2	26.4 (4.8)

Vertical lines demonstrate no significant difference at ($p<0.05$).

Table 4: *Cervical Microleakage*

Adhesive	Amalgam % Microleakage (SD)	Adhesive	Composite % Microleakage (SD)
Prime and Bond/Advance	2.4 (1.0)	OptiBond FL	0.4 (1.0)
Scotchbond MP Plus	3.3 (3.0)	Prime and Bond	1.4 (2.0)
One-Step/Resinomer	3.6 (2.0)	One-Step Universal	2.5 (3.0)
OptiBond FL	4.3 (3.0)	Scotchbond MP Plus	2.6 (3.0)
Clearfil LB2	4.5 (4.0)	Clearfil LB2	5.1 (6.0)
Amalgambond/HSP	5.7 (5.0)	Amalgambond	6.6 (5.0)
Tenure Quik	7.1 (2.0)	Tenure Quik	7.6 (10.0)
Copalite (Control)	16.2 (8.0)	Acid Etch (Control)	50.5 (27.0)

Vertical lines demonstrate no significant difference at ($p<0.05$).

Table 5: *Occlusal Microleakage*

Adhesive	Amalgam % Microleakage (SD)	Adhesive	Composite % Microleakage (SD)
One-Step/Resinomer	0.6 (1.0)	OptiBond FL	0.0 (0.0)
Clearfil LB2	1.1 (3.0)	Scotchbond MP Plus	0.0 (0.0)
Prime and Bond/Advance	1.2 (1.0)	One-Step Universal	0.0 (0.0)
Amalgambond/HSP	1.3 (2.0)	Prime and Bond	0.0 (0.0)
Copalite (Control)	2.3 (4.0)	Clearfil LB2	0.0 (0.0)
Scotchbond MP Plus	3.1 (3.0)	Tenure Quik	2.4 (7.0)
OptiBond FL	3.9 (4.0)	Amalgambond	2.4 (6.0)
Tenure Quik	4.1 (4.0)	Acid Etch (Control)	6.0 (11.0)

Vertical lines demonstrate no significant difference at ($p<0.05$).

Table 6: *Total Microleakage*

Adhesive	Amalgam % Microleakage (SD)	Adhesive	Composite % Microleakage (SD)
Prime and Bond/Advance	3.4 (2.0)	OptiBond FL	0.4 (1.0)
One-Step/Resinomer	4.1 (2.0)	Prime and Bond	1.4 (2.0)
Clearfil LB2	5.6 (5.0)	One-Step Universal	2.5 (3.0)
Scotchbond MP Plus	6.3 (4.0)	Scotchbond MP Plus	2.6 (3.0)
Amalgambond/HSP	7.0 (6.0)	Clearfil LB2	5.1 (6.0)
OptiBond FL	8.3 (6.0)	Amalgambond	9.1 (7.0)
Tenure Quik	11.2 (4.0)	Tenure Quik	10.0 (16.0)
Copalite (Control)	18.5 (9.0)	Acid Etch (Control)	56.6 (25.0)

Vertical lines demonstrate no significant difference at ($p<0.05$).

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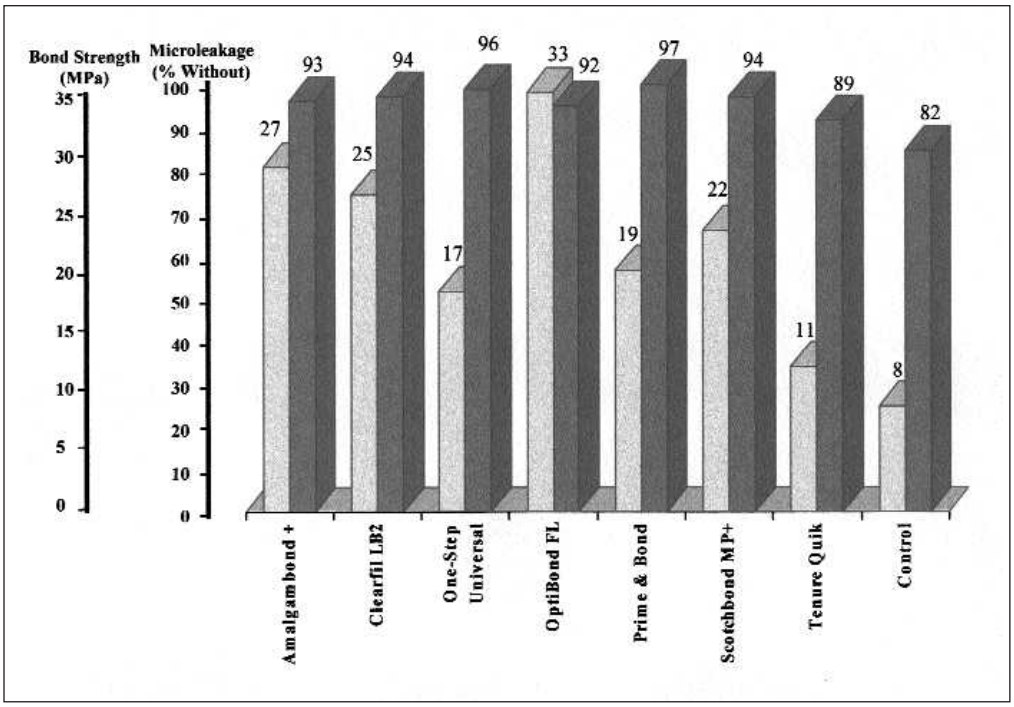

Figure 2. *Amalgam bond strength and microleakage.*

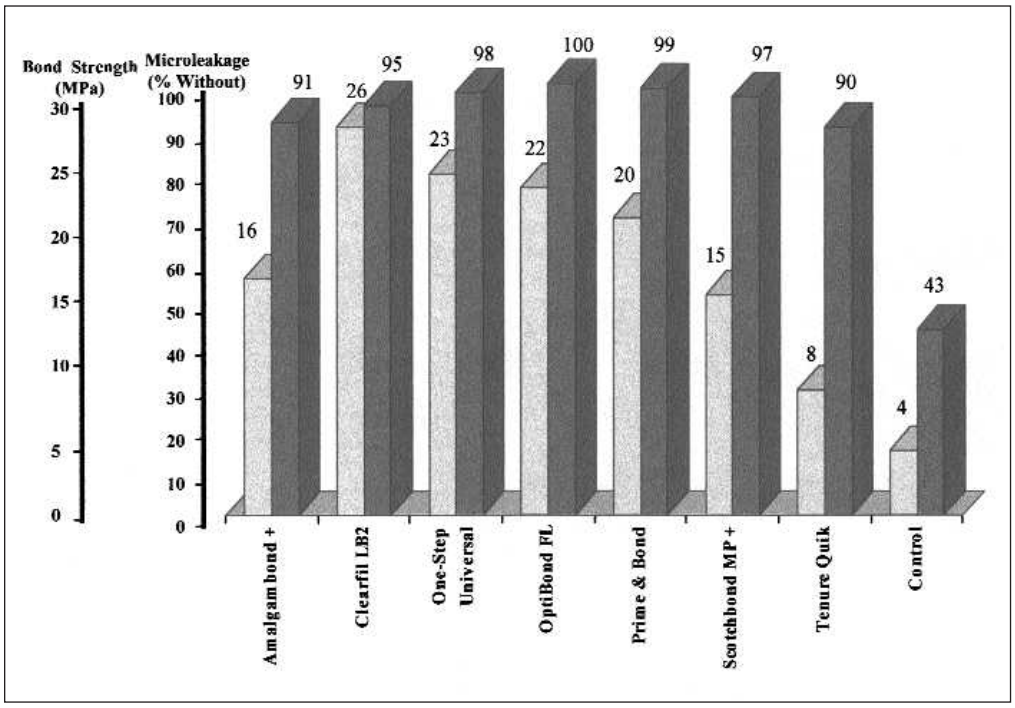

Figure 3. *Resin composite bond strength and microleakage.*

RESULTS

Table 3 displays the means and standard deviations for bond strength of amalgam and resin composite bonded to dentin using the various multi-purpose adhesives. Two-factor ANOVA and Student-Newman-Keuls tests revealed an interaction between restorative material and adhesive system with a statistically significant difference among dental adhesives ($p<0.05$). The results also demonstrate an increase in bond strength with the use of a multi-purpose adhesive system as compared to the control. In this study, mean amalgam shear strength values for all adhesives (21.9 MPa) were higher than mean resin composite shear strength values (18.6 MPa) and significantly different from each other ($p<0.05$).

Fracture sites were evaluated for each of the adhesive systems within the bond strength groups. For OptiBond FL, 100% of the bond failures were cohesive through the bonding agent, demonstrating remnants of adhesive material dispersed equally between both dentin and restorative material. All other adhesives, with the exception of Tenure Quik, were primarily (70% or greater) cohesive failures. Tenure Quik demonstrated 60 and 90% adhesive failure for resin composite and amalgam, respectively. Both controls (37% phosphoric etch for resin composite and copal varnish for amalgam) produced fracture types that were 100% adhesive in nature with the failure located at the tooth-to-composite interface or the tooth-to-amalgam interface. These data suggest that the highest bond strengths were reported when the majority of failures were cohesive in nature, and the weakest bonds were associated with a high percentage of adhesive failure.

Among the adhesive systems tested, OptiBond FL produced statistically the highest average shear strength (33.0 MPa) for amalgam bonded to dentin. A statistically significant difference in bond strength was

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observed between OptiBond FL and the next highest group. This group included Amalgambond Plus (27.0 MPa), Clearfil Liner Bond 2 (24.5 MPa) and Scotchbond Multipurpose Plus (22.3 MPa), with statistically similar means but all statistically different from OptiBond FL.

For the resin composite restorations, Clearfil Liner Bond 2 (26.4 MPa), One-Step Universal (22.5 MPa) and OptiBond FL (21.9 MPa) produced the highest shear strengths between composite and dentin, though they were not significantly different from each other. Although the individual performance of each adhesive varied with the type of restorative material, OptiBond FL demonstrated the highest shear bond with both the amalgam and resin composite restorations.

The percent microleakage and standard deviations at both the cervical and occlusal margins of the samples are reported in Tables 4 and 5. Leakage at the cervical (cementum) margin was greater than at the occlusal (enamel) margin for 81% of the samples. Mean total microleakage for the amalgam restorations (6.4%) was greater than the mean total microleakage for resin composite restorations (4.3%). However, these values were not significantly different from one another.

Table 6 displays the means and standard deviations for the total microleakage. Total microleakage was greatest in the resin composite control group with 57% of the restoration-to-tooth interface demonstrating dye penetration. The amalgam restorations without adhesive (control) yielded an average total microleakage of only 18%, demonstrating less dependence on the adhesive for marginal seal with amalgam than with resin composite. Total microleakage was statistically lower for each of the restorative material/adhesive system combinations compared to the control samples.

Figures 2 and 3 show juxtaposed values for microleakage and bond strength for each of the adhesive materials by restoration type (amalgam, resin composite). For the purpose of comparison, bond strength is reported in MPa units and microleakage is reported in percent interface with no evidence of leakage. Some relationship is apparent between methodologies, but there appears to be no consistent pattern between the two sets of test values for the group of adhesives measured in this study.

DISCUSSION

The rationale for using adhesive systems in restorative dentistry originates from multiple applications. Universal adhesives have been recommended for bonding porcelain, resin composite, alloy and amalgam to both dentin and enamel. One reported benefit of these agents is the ability to seal dentin, which results in a reduction of interfacial microleakage and pulpal sensitivity. Failure to seal the restoration at the cavosurface margin from the ingress of bacteria and oral fluids may contribute to staining, adverse pulpal response, postoperative sensitivity and recurrent caries (Duke, 1993). An additional advantage of these adhesive techniques is increased bond strength for greater structural integrity of both tooth and restoration (Boyer & Roth, 1994). These applications represent the two main purposes for using adhesives in restorative dentistry, for example, marginal seal and retention.

The issue for the clinician in selecting a dental adhesive, especially in the absence of long-term clinical trials, is (1) how to interpret the data presented from a variety of methodologies for the same test (that is, planar shear vs punch-out) and (2) how to select the appropriate test performed *in vitro* (that is, bond strength vs microleakage) to predict a particular clinical outcome.

Even within a similar test parameter, that is, bond strength, variable methodologies do not allow numerical values (MPa) to be compared for materials between studies. For example, resin composite bond strengths have generally been reported to be greater than amalgam bond strength values with the planar shear test. In contrast, the results reported in this study demonstrated higher bond strengths for the amalgam restorations than the composite restorations with the punch-out method. One reason for this difference may be the unique nature of the punch-out shear test, which uses a three-dimensional model as opposed to the planar shear test. Frictional resistance inherent in the punch-out method and polymerization shrinkage related to the increased surface of the bonded area are two factors which may explain this difference. Although the planar shear test may be more acceptable to the purist for evaluation of bond strengths, the punch-out test does represent a more clinically relevant design.

The results of this study predict a superior outcome with the use of an adhesive system based on both bond strength and microleakage tests performed *in vitro* as compared to a control. The results also suggest that the adhesive provides greater benefit for the resin composite restoration than for the amalgam restoration based upon these tests.

Selecting an adhesive material based on the results of tests performed *in vitro* requires careful consideration of the requirements of the specific clinical application. For example, a complex amalgam may require high bond strength values to assist in retention, but success will be less dependent on the ability to seal the restoration at the cavosurface margin. Repair of an incisal edge with resin composite may require high resistance to microleakage for maintenance of esthetics, with less dependence upon dentin bonding. Should fracture of the restoration occur, adhesive failure between the dentin and the restorative material may be preferable to conserve tooth structure. For the porcelain inlay,

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both microleakage and bond strength are important. Bond strength is required for maintaining structural integrity of the tooth as a whole, while microleakage is an important consideration for preserving the marginal seal due to less than ideal marginal adaptation of the porcelain material.

The relationship between the two methodologies appears to be inconsistent from the data presented (Figures 2 and 3). Although the results demonstrate that using an adhesive system will both increase bond strength and decrease microleakge, the bond strength test was more sensitive based upon a greater number of statistically significant differences among products. The two tests evaluate different, yet related properties. When using these two methodologies as predictors of clinical success, the clinician should consider the specific requirements of the intended clinical application. Although dentin adhesion may persist despite partial bonding and pronounced microleakage, this success alone may be insufficient to fully characterize all the factors desirable for that bond *in vivo*.

CONCLUSIONS

In this study the use of an adhesive significantly influenced bond strength and extent of microleakage in both amalgam and resin composite restorations. Although trends can be seen from the reported findings, individual performance of each adhesive varied with respect to restorative material and test method applied. Because much of what we advocate clinically is based on tests performed *in vitro*, future investigations should include designing *in vitro* methodologies that correlate with clinical trials. Additionally, investigations comparing methodologies for bond strength evaluation will be needed to determine the efficacy of a standardized test.

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Color Stability of Fluoride-Containing Restorative Materials

G Iazzetti • JO Burgess
D Gardiner • A Ripps

Clinical Relevance

There are visual color differences between products of the same vita shade and the color stability and stain resistance varies between materials.

SUMMARY

Six fluoride-releasing matrials of shade A3 were tested: one glass ionomer (Fuji IX), one resin-modified glass ionomer (Photac-Fil), two compomers (F 2000 and Dyract AP) and two composites (Tetric Ceram and Solitaire). Disk-shaped specimens of each material were prepared according to manufacturer's instructions, polished and L*a*b* baseline measurements taken. Specimens were randomly divided into two groups and given four different treatments of UV light exposure and immersion in a staining solution. Chromo Meter color measurements were taken following each treatment.

Two-way ANOVA and Duncan Multiple Range post-hoc tests were used to compare color changes as a function of the four treatment conditions and one-way ANOVA was used to compare materials for each treatment separately. The results showed significant difference in shade A3 between products. In general, the hydrophobic materials showed greater color stability and stain resistance than the hydrophilic materials. Tetric ceram had the best color stability and stain resistance, while Fuji IX had the least.

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INTRODUCTION

Tooth-colored restorative materials are used to cosmetically restore teeth with little or no tooth preparation. Fluoride has been incorporated into some esthetic restorative materials to reduce recurrent caries around esthetic restorations (Haveman, Burgess & Summitt, 1999). Different classes of fluoride-releasing materials have been developed, including fluoride-releasing composite resins, compomers, glass ionomers and resin-modified glass ionomers. However, an earlier study found

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Table 1: *Fluoride Releasing Materials Used*

Material	Manufacturer	Classification
Fuji IX	GC-Chicago, IL	Glass Ionomer
Photac-Fil	ESPE – Dental AG, Seefeld-Germany	Resin modified glass ionomer (RMGI)
F 2000	3M, St Paul, MN	Compomer
Dyract AP	LD Caulk, Milford, DE	Compomer
Solitaire	Kulzer, South Bend, IN	Composite
Tetric Ceram	Ivoclar, Amherst, NY	Composite

that the color stability of fluoride-releasing materials, particularly resin-modified glass ionomers, were less than ideal (Davis, Friedl & Powers, 1995). Since fluoride-releasing materials have varying composition ranging from hydrophobic to hydrophilic, they may not have equal color stability.

An unacceptable color match is a major reason to replace anterior fillings (Kroeze & others 1990). Intrinsic factors due to changes in the filler, matrix or silane coating or extrinsic factors, such as adsorption or absorption of stains, may cause discoloration of esthetic materials. The intrinsic color of esthetic materials may change when the materials are aged under various physical-chemical conditions, such as ultraviolet exposure, thermal changes and humidity. Therefore, discoloration of dental restorative materials has a multifactorial etiology.

This *in vitro* study measured and compared the color stability of six materials representing four different classes of fluoride-releasing esthetic restorative materials.

METHODS AND MATERIALS

Six materials (Table 1) of shade A3 were tested. One glass ionomer (Fuji IX), one resin-modified glass ionomer (RMGI) (Photac-Fil), two compomers (F 2000 and Dyract AP) and two composites (Tetric Ceram and Solitaire). Ten disk-shaped specimens, 2 mm in diameter and 2 mm in thickness, were prepared in split Teflon molds pressed between transparent plastic strips and glass plates to obtain a uniformly smooth specimen surface. The materials were manipulated and polymerized according to the manufacturers' instructions. An Elipar II (ESPE America) light-curing unit was used to polymerize the light-cured materials. Light output was measured with a power-intensity meter (Litex- Dental America) prior to curing each group of specimens to ensure light output above 500mW/cm$_2$. After they were cured, all specimens were polished with Sof-Lex discs (3M, St Paul, MN), and the color of each was measured with a Chroma Meter (model CS-100, Minolta Corp, Osaka, Japan) against a white background to obtain baseline values (L*a*b*).

The specimens were randomly separated into two groups and given four different treatments. Group A was subjected to ultraviolet (UV) light exposure at 37°C for 24 hours and subsequently immersed in a staining solution (instant coffee mixed with soluble tea and cranberry juice) and stored in the solution for one week at 37°C. Group B was placed in the staining solution for one week followed by 24 hours UV exposure. The color measurement was taken after each treatment. For group A, it was taken after 24 hours UV exposure (E1) and 24 hours UV plus one week in the staining solution (E2), and for group B it was taken after one week in the staining solution (E3) and one week in the staining solution plus 24 hours UV exposure (E4) (Figure 1). Before measurements, the specimens that were in the staining solution were rinsed with tap water and air dried. The Chroma Meter, specimen and light source were positioned in a uniform manner for all measurements (Figure 2).

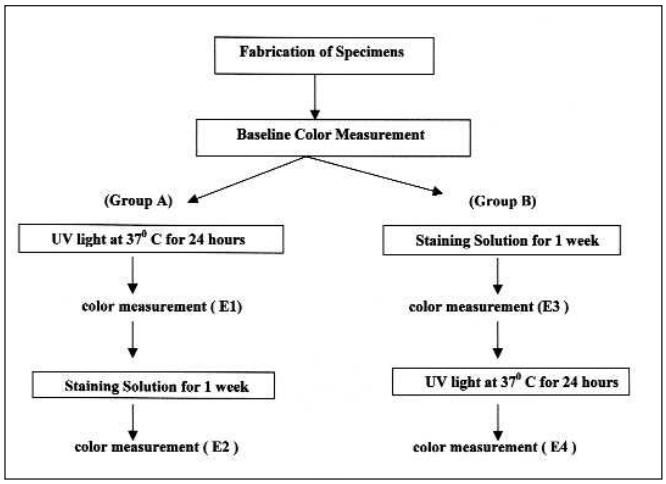

Figure 1. *Staining treatment and color measurement of all specimens.*

Figure 2. *Chroma Meter position with light source to measure L*a*b* value.*

L* a* b* values defined by CIE (Commission Internationale de l'Eclairage) were measured with the Minolta Chroma Meter. L* refers to the lightness coordinate, and its value ranges from zero (perfect black) to 100 (perfect white). The a* and b* are chromaticity coordinates in the red-green axis and the yellow-blue axis, respectively. Positive a* values indicate a shift to red; negative values indicate a shift to green. Similarly, positive b* values indicate the yellow

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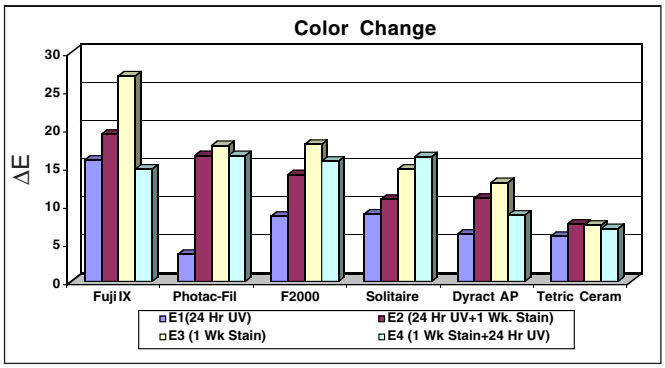

Figure 3. *Color change produced by four treatments on six materials.*

color range, and negative values indicate the blue color range. The values for both a* and b* are equal to 0 at the intersection, increase indefinitely in the red and yellow directions and decrease indefinitely in the blue and green directions. The differences in the lightness and chromaticity values (L*, a*, b*) were determined, and the total color change after aging (E) was calculated using the color difference formula:

$$\Delta E = [(L^*o - L^*i)\ 2 + (a^*\ o - a^*\ i)\ 2 + (b^*\ o - b^*\ i)\ 2]$$

Two-way analysis of variance (ANOVA) and Duncan Multiple Range post-hoc tests were used for the statistical comparison of color changes for the materials and as a function of the four different environmental conditions, and the baseline values were obtained immediately after curing. The analysis was done for overall color change and for each parameter (L* a* b*) separately. One-way ANOVA was then used to compare the materials for each treatment separately.

RESULTS

Two-way ANOVA comparing differences in ΔE among the products and treatment conditions was significant ($p<.0001$) for products and for treatment, and there was significant interaction between materials and treatments ($p<.0003$). The Duncan Multiple Range follow-up comparisons revealed the following: when material was considered without regard to treatment, the composite, Tetric Ceram, provided the greatest color stability, and the glass ionomer, Fuji IX, provided the least (Figure 3). When only treatment conditions were compared, one week in the staining solution (E3) produced the greatest color change while 24 hours of UV exposure (E1) produced the least. There was no statistically significant difference between treatment E2 and E4; that is, reversing the treatment order from UV to stain or from stain to UV had no effect. The significant interaction indicates that the ranking of the materials for color stability varied depending on the treatment.

The values for each of the L* a* b* parameters of color were analyzed separately. The two-way ANOVA revealed a significant difference for material and treatment for L* ($p<.0001$), a* ($p<.0001$) and b* ($p<.02$ for material) and ($p<.0001$ for treatment). For Materials: The follow–up comparisons revealed that Tetric Ceram had the least darkening and Fuji IX the greatest (ΔL*). All materials except Tetric Ceram became greener; that is, Δa* became more negative. In all treatments, all materials became yellower; that is, Δb* values became more positive.

For Treatments: The Duncan Multiple Range test showed that ΔL* changed the least with the UV treatment (E1). Treatment E2 (24 hours UV + one week stain), E3 (one week stain) and E4 (one week stain + 24 hours UV) were not significantly different. For Δa*, treatment E4 (one week in stain + 24 hours UV) produced the greatest changes. For Δb*, the treatment E2 (24 hours UV + one week stain) and E3 (one week stain) showed the greatest yellowing (Δb* became more positive) followed by E4 and E1.

ΔE, ΔL*, Δa* and Δb* values were compared among materials for each treatment separately using one-way ANOVA. In addition, the treatments were compared separately for each material. The results of the Duncan Multiple Range follow-up tests for these comparisons are reported in Table 2 and Table 3.

For the comparisons of materials in each treatment, it is important to note the following results: for ΔE in E1, E2 and E3 treatments, Fuji IX showed the greatest color change. For ΔL* in E1, E2 and E3 treatments, Fuji IX became darker than the other materials. For Δa* color dimension, Fuji IX remained relatively stable compared to the other materials. For Δb* E1 treatment, Fuji IX became more blue, but in E3 Fuji IX became more yellow than the other materials (Table 2).

For treatment comparisons of each individual material, there was substantial variation in color stability from one material to the next. For example, in ΔE Tetric Ceram

Table 2: *Results of Color Difference Among Products for Each Treatment*

Treatments	ΔE	ΔL*	Δa*	Δb*
E_1	Fu So F Dy Te Ph	Te Ph Dy So F Fu	Dy Te Ph Fu F So	So F Te Dy Ph Fu
E_2	Fu Ph F Dy So Te	Te Dy Ph So F Fu	Te Dy So Fu F Ph	Ph F Fu Dy Te So
E_3	Fu F Ph So Dy Te	Te Dy Ph So F Fu	Te Fu Dy So Ph F	Fu Ph FDy So Te
E_4	Ph So F Fu Dy Te	Te Dy Fu Ph F So	Te Fu Ph Dy So F	Ph F Te Fu Du So

Tetric (Te); Solitaire (So); Dyract Ap (Dy); F 2000 (F); Photac-Fil (Ph); Fuji IX (Fu)
E_1(24 hrs); E_2 (24 hrs + 1 w stain); E_3 (1 w stain); E_4 (1 w stain + 24 hrs UV)
Materials connected by solid line are not significantly different

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Table 3: *ΔE, ΔL*, Δa*, Δb*, Intergroup Differences After Four Treatments*

After 24 hrs UV	Fuji IX	Photac Fil	F2000	Solitaire	Dyract AP	Tetric
ΔL*	-13.75(4.64)^{D,b,a}	-1.75(2.75)A,B,a	-5.82(2.38)^{C,c,a}	-5.27(1.31)^{B,C,a}	-3.44(1.48)^{A,B,C,a}	0.04(1.47)^{A,a}
Δa*	-0.69(0.28)A,B,a,b	-0.68(0.48)A,B,a	-0.82(0.4)^{A,B,a}	-0.97(0.17)^{B,a}	-0.39(0.30)^{A,b}	-6(0.53)^{A,B,b}
Δb*	-7.02(2.94)C,d	-0.9(l.9)B,b	6.02(l.93)^{A,b}	6.83(0.5)^{A,a}	4.88(1.78)^{A,b}	5.64(2.60)^{A,a}
ΔE	115.9(3.56)^{C,a}	3.62(0.71)^{C,b}	8.56(2.59)^{B,c}	8.76(0.47)^{B,b}	6.18(1.27)^{B,C,c}	5.90(2.44)^{C,a}
After 24hrs UV + 1 w stain						
ΔL*	-15.06(4.11)^{C,a}	-7.86(3.52)^{A,b}	-7.69(2.76)^{A,a}	-9.37(1.39)^{B,b}	-5.66(2.07)^{A,a}	-.34(2.07)^{A,b}
Δa*	-1.13(1.42)^{C,b}	-2.39(0.77)^{D,b}	-1.60(0.43)^{C,D,b}	-0.66(0.44)^{C,a}	0.35(0.59)^{B,a}	1.62(0.47)^{A,a}
Δb*	11.25(5.09)^{A,B,b}	13.97(3.85)^{A,a}	11.42(0.76)^{A,B,a}	5.26(0.86)^{C,a}	9.25(2.73)^{B,C,a}	5.66(2.32)^{C,a}
ΔE2	19.27(4.76)^{A,a,b}	16.50(4.02)^{A,B,a}	13.98(2.04)^{B,C,b}	10.80(l.47)^{C,D,b}	10.92(3.22)^{C,D,a,b}	7.51(2.52)^{D,a}
After 1w Stain						
ΔL*	-14.5(12.89)^{B,a}	-8.63(3.59)^{A,B,b}	-12.93(1.56)^{A,B,b}	-12.15(3.12)^{A,B,c}	-6.79(2.79)^{A,B,a}	-.23(2.10)^{A,b}
Δa*	0.25(0.69)^{B,a}	-2.29(0.79)^{D,b}	-2.60(0.36)^{D,c}	-1.09(0.7)C,a	-0.77(0.49)^{C,b}	1.45(0.76)^{A,a}
Δb*	20.62(5.61)^{A,a}	15.28(3.47)^{B,a}	12.12(2.87)^{B,C,a}	7.84(3.8)^{C,D,a}	10.74(1.34)^{B,C,a}	4.20(2.6)^{D,a}
ΔE3	6.91(8.97)^{A,a}	17.86(4.33)^{B,a}	17.98(2.87)^{B,a}	14.74(3.94)^{B,a}	12.97(1.47)^{B,C,a}	7.31(1.95)^{C,a}
After 1 w Stain+ 24 hrs UV						
ΔL*	-11.32(11.46)^{B,C,a}	-11.88(6.15)^{B,C,b}	-12.87(l.9)^{B,C,b}	-14.97(l.64)^{C,d}	-6.44(2.84)^{A,B,a}	0.05(3.27)^{A,a}
Δa*	-1.55(0.56)^{B,b}	-1.89(1.35)^{B,a,b}	-3.72(0.64)^{C,d}	-3.30(0.18)^{C,b}	-1.92(0.62)^{B,c}	1.48(0.67)^{A,a}
Δb*	5.19(1.31)^{B,c}	10.70(3.81)^{A,a}	7.86(3.14)^{A,B,b}	4.83(3.80)^{B,a}	5.16(2.20)^{B,b}	5.71(1.06)^{B,a}
ΔE4	14.71(7.42)^{A,b}	16.51(6.17)^{A,a}	15.75(2.35)^{A,a,b}	16.33(2.45)^{A,a}	8.67(3.03)^{B,b,c}	6.68(0.33)^{B,a}

Comparisons between products are shown with a capital letter. Comparisons between treatments are represented with a lower case letter.

showed no significant difference among treatments, whereas in ΔL* Solitaire was significantly different in all four treatments. See Table 3 for all of the individual comparisons.

DISCUSSION

Color stability is critical to the long-term esthetics of restorations and has been previously studied *in vitro* for a variety of restorative materials. This study measured the color stability of different classes of fluoride-releasing materials. It measured and compared their susceptibility to staining in a staining solution at 37°C as well as by assessing their color changes during ultraviolet-light exposure at 37°C.

Discoloration can be evaluated with various instruments. Since instrument measurements eliminate the subjective interpretation of visual-color comparison, spectrophotometers and colorimeters have been used to measure color changes in dental materials (Okubo & others, 1998; Satou & others, 1989; Seghi, Johnston & O'Brien, 1986). The general population can distinguish between restorations of teeth if the color difference ΔE is 3.3 or greater (Ruyter, Nilmer & Moller, 1987). In our study, it was generally observed that specimens became darker, greener and yellower after treatments and that all specimens had E's greater than 3.3.

Data collected by colorimeter can be significantly altered by the inability of the colorimeter to read translucent materials, standardized illuminating light emitted from the device and background (Johnston & Reisbick, 1997; Powers, Dennison & LePeak, 1978a; van der Burgt & others, 1990). When measuring reflective surfaces, the measured color will depend on both the actual colors of the surface and the lighting conditions under which the surface is measured. Thickness and smoothness of the specimen surface also affect color. Smoothness of the specimen reflects light differently so that rougher specimens appear darker (lower values) (Okubo & others, 1998; Seghi, Johnston & O'Brien, 1986).

Intrinsic and extrinsic factors may cause discoloration of esthetic materials. The intrinsic factors involve the

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discoloration of the material itself by the alteration of the matrix interface, matrix or fillers and oxidation in the structure of the material of unreacted pendant methacrylate groups. For example, urethane dimethacrylate seems more stain resistant than Bis-GMA (Asmussen, 1983: Khokhar, Razzoog & Yaman, 1991). The intrinsic color can be altered as a result of accelerated aging conditions, such as ultraviolet irradiation (Ferracane, 1985; Powers & others, 1978b). Extrinsic factors producing discoloration include staining by adsorption or absorption of stain. The composition and size of the filler particles affect surface smoothness (van Noort and Davis, 1984) and the susceptibility for extrinsic staining (Peutzfeldt & Asmussen, 1990; Seghi, Gritz, Kim, 1990; Shintani & others, 1985). The relative unsatisfactory behavior of Solitaire could be attributed to the porosity of the glass particles of the filler (Figure 4). Finishing and polishing procedures may also influence surface smoothness, which is related to early discoloration (Hachiya & others, 1984; Shintani & others, 1985). Rough surfaces mechanically retain surface stains more than smooth surfaces. To achieve less color change, special attention should be paid to obtaining a perfect surface finish. Roughening of the surface caused by wear and chemical degradation can also increase extrinsic staining (Van Groeningen, Jongebloed & Arends, 1986).

Previous studies have reported that composites change color in the oral environment due to stain accumulation, dehydration on the surface, water sorption in the matrix, chemical breakdown, surface degradation, leakage, poor bonding and surface roughness (Powers & others, 1978b). Hydrophilic materials stain more than hydrophobic materials (Douglas & Craig, 1982). RMGI, due to their hydrophilicity and greater surface degradation, had greater color change than composites after accelerated aging (Doray & others, 1997; Powers & others, 1988). A progressive cross-linking reaction continues to occur up to one week after photo-activation (Watts, Amer & Combe, 1987).

Whereas changes in surface roughness of composites were attributed to wear of the resin and exposure of filler particles, surface roughness in RMGI seems to be caused primarily by cracking. This cracking may indicate that although the new RMGI have improved mechanical properties compared to traditional glass ionomers, they still dehydrate after setting and drying (Christensen, 1993). The micro-cracks or the interfacial gaps at the interface between filler and matrix allow stain penetration and discoloration (Mair, 1991).

Even though the same shade (A3) was used for each restorative material, it was visually obvious that shade differences were present at baseline. When a statistical analysis was used to examine whether these differences were significant at baseline for the L* a* b* values, significant differences were found ($p<.01$). Dyract AP and Tetric Ceram were the darkest and registered the lowest L* values (darker) than all other materials at baseline, but all values L* a* b* were significantly different.

CONCLUSIONS

1. Tetric Ceram was the most stain resistant and color stable of all the fluoride-releasing materials examined in this study.
2. Fuji IX (GI) was the least color stable with significantly more staining than all materials.
3. In general, hydrophobic materials (composite resin) show greater stain resistance and color stability than hydrophilic (RMGI and GI) materials.
4. Even though Solitaire is a composite resin, its stain resistance was poor, perhaps due to its porous filler.
5. Shade A3 differs significantly from one manufacturer to another.

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The Effect of Tooth Preparation on Microleakage Behavior

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Clinical Relevance

Teeth bonded and restored with composite resin exhibited less microleakage with acid-etched cavities than with non-etched cavities irrespective of the method of cavity preparation.

SUMMARY

Many factors contribute to the microleakage of a restoration. One of the more important is the method of cavity preparation. This study compared the microleakage behavior of composite restorations placed in cavities prepared by different techniques. It also compared and correlated the microleakage data produced by an electrochemical vs a staining technique.

Class V cavities were prepared in 48 premolars by four techniques: (1) tungsten carbide bur in a high-speed handpiece followed by acid etching; (2) air abrasion (27 µm Al_2O_3) followed by acid etching; (3) air abrasion (50 µm Al_2O_3) and (4) air abrasion (27 µm Al_2O_3), with n=12 in each group. All teeth were restored with Prime and Bond 2.1 and Tetric Flow, then thermocycled between 5° and 55°C for 5000 cycles with a one minute dwell at each temperature. After thermocycling, a PVC-covered Cu wire was inserted apically into the pulp chamber of each tooth and sealed into position. Leakage was continuously followed by a conductimetric method for 75 days. The teeth then were immersed in 50% $AgNO_3$ for two hours, rinsed in distilled water for 60 seconds, then placed in a rapid photographic developer solution for two hours, followed by rinsing and sectioning for microscopic examination. Electrochemical data were examined by ANOVA and Newman-Keuls multiple comparison tests, while Kruskal-Wallis and Rank Sum Difference tests were used on the staining evaluations. Spearman's rho test was used to correlate the two test techniques.

Electrochemical data for cavities prepared with a bur or air abrasion followed by acid etching prior to restoration showed significantly less ($p \leq 0.05$) microleakage (mean leakage currents of 1.89 & 1.57 µA, respectively) than teeth prepared with air abrasion alone (mean leakage currents of 3.60 & 3.40 µA, respectively). Rank sum $AgNO_3$ staining data (196 & 242 vs 371 & 368) supported these findings. The correlation between the electrochemical and staining data

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was significant ($p \leq 0.05$) for all four groups of test specimens.

INTRODUCTION

Modern adhesive dentistry has a significant number of advantages for the clinician, including convenience, effectiveness, efficiency and conservation of hard tissue. The latter benefit arises because adhesive restorations eliminate the need for the classical Black retentive cavity preparation. Thus, after caries removal, cavity preparation, refining and margination are minimized although the cavity requires conditioning prior to restoration placement.

Adhesive dentistry relies upon a micro-mechanical bond between tooth structure and restorative material through retention of the resin within acid etch pits in the surface (Buonocore, 1955; Retief & Denys, 1989; Galan & Lynch, 1993). Originally, adhesive dentistry applied only to enamel surfaces, but acid conditioning of both enamel and dentin, as well as bonding to dentin is now commonly accepted (Retief & Denys, 1989; Bertolotti, 1991; Söderholm, 1995). The concepts of adhesive dentistry are generally applied to cavities prepared with the traditional handpiece and dental bur. However, alternative systems of dental cutting have been suggested for cavity preparation, notably air abrasion, which was first proposed in 1943 and refined over subsequent decades (Black, 1945; Black, 1955; Rosenberg, 1995). Although the use of air abrasion for caries removal and cavity preparation had many advantages, interest diminished with the advent of the air-turbine high-speed handpiece combined with the inherent problems associated with the technology available at that time. In particular, the early air-abrasion technology suffered from a lack of high-speed evacuation and inadequate control of particle flow. Interest in air abrasion has reawakened with the development and introduction of modern high efficiency units (Myers, 1994; Goldstein & Parkins, 1994), while the rounded line angles and cavity walls inherent to abrasion-cut cavities are less important considerations with adhesive dentistry.

Cavity preparation by air abrasion introduces a surface roughening with a groove width of 1-20 µm (Laurell & Hess, 1995), which led to suggestions that the abraded surface is suitable for direct bonding techniques. Various studies indicated that while bond strengths to air-abraded enamel were comparable to those achieved with acid etched surfaces, higher bond strengths to dentin were found with abraded than etched surfaces (Laurell, Lord & Beck, 1993; Keen, von Fraunhofer & Parkins, 1994). In contrast, several workers have reported that satisfactory bond strengths are only achieved with air-abraded surfaces when they are also acid etched (Roeder & others, 1995; Brockmann, Scott & Eick, 1989; Brown & Barkmeier, 1996).

A secondary but arguably more important facet of adhesive dentistry is that of marginal seal of the restoration. Loss of seal integrity, often manifested as microleakage, is thought to be a primary cause of secondary caries, post-operative sensitivity and staining, ultimately leading to clinical failure. Consequently, reducing or eliminating microleakage around restorations is an important objective in clinical practice and has resulted in numerous investigations of bonded restoration microleakage (Wu, Cobb & Dermann, 1983; von Fraunhofer & Hammer, 1984; Dumsha & Biron, 1984; Kanca, 1989; Fortin & others. 1994). There have been, however, relatively few studies of microleakage occurring with restorations placed in cavities prepared by air abrasion. One reported study (Haws & others, 1996) on pit-and-fissure sealants indicated that teeth prepared with air abrasion alone experienced significantly more microleakage than those prepared with air abrasion and subsequent acid etch or those only acid etched. It was concluded that acid etching alone or in combination with air abrasion is a better option than air abrasion alone in preventing leakage of pit-and-fissure sealants.

Overall, the literature indicates some uncertainty over the efficacy of air abrasion as a means of preparing hard dental tissue for adhesive dentistry, and the consensus of data suggests that surfaces prepared by air abrasion alone do not achieve an adequate bond strength with resinous materials. Furthermore, indications show that acid etching combined with a priming/ bonding agent is required to achieve maximal bond strengths with air-abraded enamel and dentin. Notwithstanding the above, it is unclear what the effect of air abrasion alone, or in combination with acid etching is upon microleakage at the tooth/resin interface. This investigation studied this question.

A second question integral to the study was how best to evaluate microleakage. It is often assessed by penetration methods using radioisotopes, dyes or silver nitrate as the diffusing species. Silver nitrate staining, for example, has been used in several leakage studies, particularly in endodontics (Dumsha & Bryon, 1984) and is a widely accepted test methodology (Wu & others, 1983). Penetration tests are very useful in characterizing the extent and location of microleakage around a restoration but suffer from the disadvantage that specimens must be sectioned to evaluate leakage. Thus, these tests are post hoc in nature, and since sectioned specimens are examined, only microleakage within a particular plane is identified. In contrast, the electrochemical method (von Fraunhofer & Hammer, 1984; Jacobson & von Fraunhofer, 1976) is a dynamic test that provides a continuous evaluation of microleakage throughout the testing period, although this approach does not identify the precise location of the leakage. Despite considerable literature on the marginal leakage associated with various

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Table 1: *Test Groups*

Group	Treatment Regimen
A	Cavity prepared with highspeed handpiece and 331 tungsten carbide bur; cavity walls etched with 37% H_3PO_4 for 30 seconds, 20 seconds water wash, dried with a cotton pellet.
B	Cavity prepared with Air Touch air abrasive system using 27 µm Al_2O_3 at 85 psi, cavity walls etched with 37% H_3PO_4 for 30 seconds, 20 seconds water wash, dried with a cotton pellet.
C	Cavity prepared with Air Touch air abrasive system using 50 µm Al_2O_3 at 85 psi only, 20 seconds water wash, dried with a cotton pellet.
D	Cavity prepared with Air Touch air abrasive system using 27 µm Al_2O_3 at 85 psi only, 20 seconds water wash, dried with a cotton pellet.

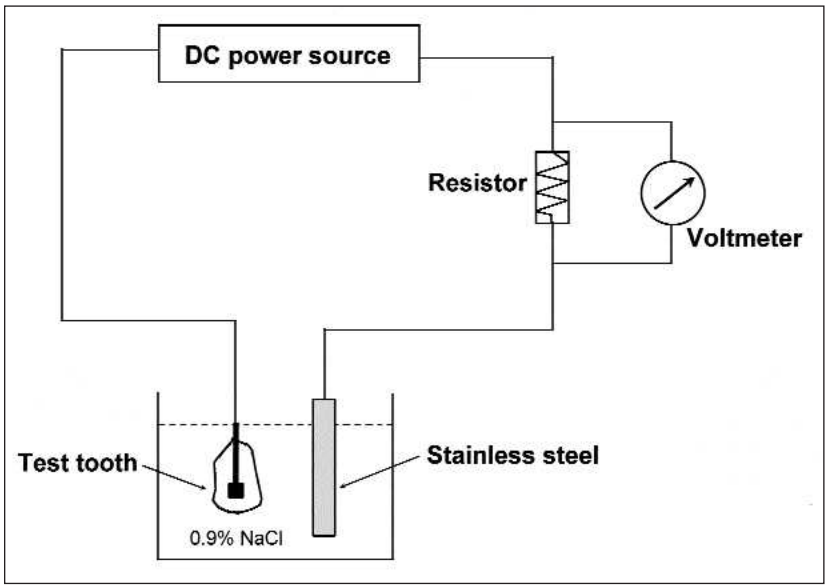

Figure 1. *Electrochemical test circuit.*

restorative materials, little attention has been given to an evaluation and comparison of the test methods, themselves. Therefore, a secondary but important aspect of this study evaluated and correlated the electrochemical and the silver nitrate staining microleakage test techniques.

METHODS AND MATERIALS

Forty-eight sound human premolars, extracted for orthodontic or periodontal reasons, were collected, randomly divided into four groups of 12 and stored in distilled water. Class V cavity preparations (3 mm in length and 2 mm wide with a depth of 2 mm) were made in each tooth. The preparations were produced with a high-speed carbide bur under water-spray coolant or were roughly prepared with a high-speed handpiece, then refined by air abrasion (Air Touch air abrasive system), Table 1. The dimensions of each cavity were verified using a digital micrometer (Mitutoyo Corp, Tokyo, Japan) to ±0.1 mm. Each tooth was then radiographed to ensure that the cavity preparation was completely surrounded by sound enamel.

The teeth were then primed and bonded (Prime and Bond 2.1, Caulk Dentsply, York, PA) and restored with composite resin (Tetric Flow, Ivoclar Vivadent, Schaan, Liechtenshein). The composite was placed in two increments and light cured with a Demetron Optilux light cure VLC 410 unit (Kerr) for 40 seconds per increment to ensure complete polymerization.

All restorations were finished with a 12-fluted gold-shank finishing bur (Midwest) followed by polishing discs (Sof-lex). Three layers of nail varnish were applied to the root surfaces and around the restorations to provide an impermeable barrier to the fluids. After restoration, the teeth were thermocycled from 5°C to 55°C for 5000 cycles using a one-minute dwell at each temperature.

After thermocycling, the root and pulpal tissues were removed from all teeth with endodontic files and the roots were prepared to reamer size #90. PVC-insulated multistrand copper wire was inserted into the root canal until the end of the wire, bared for a length of 5 mm, was firmly in contact with the roof of the tooth pulp chamber. The apical portion of the tooth-wire junction was sealed with sticky wax and three layers of nail varnish were applied to the root surfaces around the sticky wax. Following wire placement all teeth were radiographed to ensure that the thickness of the dentinal floor of the cavity was approximately 2 mm and that the bare copper was in contact with the coronal dentin.

The tooth and inserted copper wire functioned as one electrode in the test circuit, the other electrode being a strip of stainless steel tape, both immersed in 0.9% saline solution. A 10 V dc potential was applied between the two electrodes and any current flow in the external circuit was detected by voltage drop across a 1000 ohm resistor in series with the voltage source and electrodes, Figure 1. Current flow denoted the onset of leakage, while the current magnitude indicated the amount of microleakage at the margins of the restorations as well as any percolation through the bulk material. Measurements were taken for each specimen on alternate days for 75 days.

Following the electrochemical leakage study, the wires were removed and the apical portion of the tooth-wire junction sealed with sticky wax followed by application of three layers of nail varnish to ensure a good seal. Thereafter, the teeth were placed into a 50 wt % $AgNO_3$ solution at 37°C for two hours, followed by a 60 second rinse in distilled water and placed in a rapid-developing solution for two hours. The teeth were then sectioned bucco-lingually through the restoration using

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a slow-speed diamond sectioning-saw. The degree of microleakage was scored by one calibrated investigator under a stereomicroscope using a rank order scoring system. Dye penetration was scored using a 0-3 rating system: 0= no leakage, 1= leakage equal to or less than the enamel thickness, 2= leakage in dentin, 3= leakage involving the pulpal floor.

Positive controls for the study were two teeth prepared with a high-speed handpiece and bur and two teeth prepared with air abrasion, the teeth then being restored with zinc oxide-eugenol temporary cement. The negative controls were two teeth prepared with a high-speed handpiece and bur and two teeth prepared with air abrasion, the teeth being primed/bonded and restored with composite resin. The margins of the restoration and the restoration itself were painted with three layers of nail varnish to provide an impermeable barrier. The positive and negative controls were tested for microleakage with the electrochemical and the silver nitrate staining techniques described above.

Prior to starting the leakage investigation, a pilot study was performed to ensure consistency in use of the stain-scoring indices. Three teeth were prepared with air abrasion and four with a high-speed handpiece and bur, restored with composite resin and tested for microleakage using the electrochemical and silver nitrate techniques as described above. The investigator was calibrated in the use of the scoring indices for silver nitrate stained specimens by comparison with an expert researcher. Spearman's rho test, at an a priori α=0.05, was used to correlate the investigator's scores for the silver nitrate staining technique with the results obtained by the electrochemical technique.

The mean values of leakage currents and their standard deviations, obtained by the electrochemical technique, were calculated and the data analyzed by analysis of variance at an a priori α=0.05 significance level. A Newman Keuls Multiple Comparison test was used to identify any differences between the mean values.

The silver nitrate staining scores were analyzed by means of a Kruskal-Wallis test performed on the rank order data at a significance level of $p \leq 0.05$ and the Rank Sum Difference Multiple Comparison test was used to identify any differences.

RESULTS

Silver nitrate staining scores of the investigator and an expert researcher for the pilot study specimens are presented in Table 2. No differences were found between the scored values from the two investigators ($p>0.05$).

Table 2: *Pilot Study Silver Nitrate Staining Scores*

Air Abraded Specimens	Investigator	Expert
1	2	2
2	2	2
3	1	1
Highspeed Handpiece		
1	3	3
2	1	1
3	1	1
4	2	3

The positive controls demonstrated passage of maximal leakage current and complete silver nitrate penetration, while no current flow or silver penetration was observed with the negative controls. The former indicated the efficacy of test methods, while the absence of leakage with the negative controls confirmed the effectiveness of the apical and coronal seals in preventing leakage.

The time-based mean microleakage currents for the four test groups are presented in Figure 2. The curves clearly showed that non-etched teeth (Groups 3 and 4) yielded higher microleakage values than the acid etched teeth (Groups 1 and 2). The current values at 75 days, Table 3, confirm the greater leakage of the non-etched teeth ($p \leq 0.05$). No significant difference was found between Groups 1 and 2 or between Groups 3 and 4 ($p>0.05$).

The silver nitrate staining values and their rank sums are also shown in Table 3. Microleakage, using the silver nitrate technique, was detected in all but five

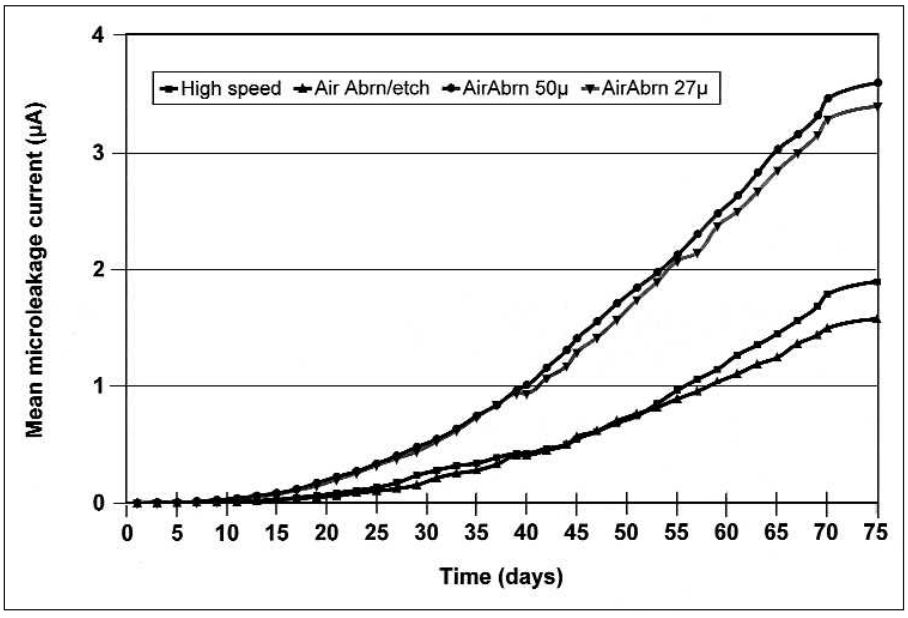

Figure 2. *Electrochemical leakage behavior over 75 days.*

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Table 3: *Microleakage Currents (μA) and Stain Scores at 75 Days*

	Group 1 (high speed/etch)		Group 2 (27 μm/etch)		Group 3 (50 μm)		Group 4 (27 μm)	
Specimen #	Current, μA	Stain (rank)	Current, μA	Stain (rank)	Current, μA	Stain (rank)	Current, μA	Stain (rank)
1	0.09	0 (3)	2.01	2 (31)	5.60	3(45.5)	3.52	2(31)
2	1.95	1(12.5)	1.08	1(12.5)	1.64	1(12.5)	2.93	2(31)
3	0.05	0 (3)	0.02	0(3)	5.26	3(45.5)	3.53	2(31)
4	2.79	2 (31)	2.09	1(12.5)	1.58	1(12.5)	3.30	2(31)
5	2.29	2 (31)	1.98	1(12.5)	2.34	1(12.5)	6.27	3(45.5)
6	2.65	2 (31)	0.05	0 (3)	1.57	1(12.5)	2.91	2(31)
7	1.24	1(12.5)	1.42	1(12.5)	2.80	2(31)	3.73	2(31)
8	1.40	1(12.5)	0.08	0(3)	5.27	3(45.5)	3.48	2(31)
9	1.08	1(12.5)	1.25	1(12.5)	3.38	2(31)	2.81	2(31)
10	2.76	2(31)	2.31	2(31)	2.86	2(31)	2.70	2(31)
11	2.97	2(31)	2.97	2(31)	5.03	3(45.5)	4.27	2(31)
12	3.41	2(31)	3.57	2(31)	5.81	3(45.5)	1.30	1(12.5)
Mean	1.89		1.57		3.59		3.40	
± S.dev	±1.12		±1.15		±1.69		±1.16	
Rank Sum		242		195.5		370.5		368

specimens, two (16.7%) in Group 1 and three (25%) in Group 2. Furthermore, no stain penetration to the pulpal floor was observed in any specimen in Groups 1 and 2. In contrast, five teeth (41.7%) in Group 3 and one tooth (8.3%) in Group 4 showed microleakage to the pulpal floor, with all teeth in these two groups exhibiting some microleakage. Group 2 teeth (air abrasion + acid etch) showed the lowest microleakage values, followed by Group 1 (high speed + acid etch). Groups 3 and 4 (air abrasion with 50 μm and 27 μm Al_2O_3 particles, respectively) showed the highest microleakage values. Kruskal-Wallis corrected for ties showed significant differences between at least some groups, $p< 0.01$. A Rank Sum Difference Multiple Comparison Test found that microleakage in Group 2 was significantly lower than that in Groups 3 and 4 ($p\leq 0.05$) but no difference between Groups 1, 3 and 4 ($p>0.05$). The statistical analyses for the two leakage test methodologies are summarized in Tables 4 and 5.

Data collected using the electrochemical and the silver nitrate techniques were correlated using a Spearman's rho test. A significant correlation between the two techniques was found for all four groups, Table 6. In Groups 1, 2 and 3, the correlation was >0.9 and significant at $p\leq 0.001$, and for Group 4 the correlation, R=0.65, was significant at $p\leq 0.05$.

DISCUSSION

This study addressed two parameters of clinical importance, notably the effect of hard tissue preparation on microleakage of composite restorations and the efficacy and accuracy of methods used to evaluate microleakage.

Microleakage, the passage of bacteria, fluids, molecules or ions between a cavity wall and the restoration, is a major concern in restorative dentistry because of its clinical sequelae, namely secondary caries, pulpal pathosis, postoperative sensitivity and pain, marginal staining, and possibly, leaching and restoration breakdown. Approaches to reduced levels of microleakage have clinical and esthetic importance but *in vitro* prediction of the clinical performance of a restoration, notably predicting the degree of microleakage that may occur over time, is difficult.

Adhesive dentistry relies upon a strong bond between restoration and tooth. Shear bond strength and marginal microleakage are two characteristics of restorative materials that are commonly evaluated by *in vitro* studies. An ideal restorative material would provide high bond strength and eliminate microleakage, but the relationship between bond strength and microleakage is not clearly understood. Logically, bond strength and microleakage should have an inverse relationship but the literature suggests a poor correlation between these parameters (Prati & others, 1990; Prati & others, 1992). It may be that there are cluster areas or foci of adhesion that hold the restorative material in place, yet allow microleakage around these areas (Fortin & others, 1994; Douglas, Fields & Fundingsland, 1989).

Acid etching is commonly used to prepare teeth for adhesive dentistry, but there is increasing interest in

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Table 4: *Statistical Analyses - Electrochemical Test*

	Group 1 (high speed/etch)	Group 2 (27 µm abrasion/etch)	Group 3 (50 µm abrasion)	Group 4 (27 abrasion)
Group 1	--	nS*	S	S
Group 2		--	S	S
Group 3			--	nS

*nS: $p>0.05$; S: $p<0.05$

Table 5: *Statistical Analyses - Silver Staining*

	Group 1 (high speed/etch)	Group 2 (27 µm abrasion/etch)	Group 3 (50 µm abrasion)	Group 4 (27 abrasion)
Group 1	--	nS*	nS	nS
Group 2		--	S	S
Group 3			--	nS

*nS: $p>0.05$; S: $p<0.05$

Table 6: *Correlations Between Electrochemical and Silver Nitrate Staining Evaluations of Microleakage*

	Group 1 (high speed/etch)	Group 2 (27 µm abrasion/etch)	Group 3 (50 µm abrasion)	Group 4 (27 abrasion)
	0.92*	0.91*	0.94*	0.65**

*: Spearman rho - $p\leq 0.001$; **: Spearman rho - $p\leq 0.05$

alternative approaches, notably air abrasion (Myers, 1994; Goldstein & Parkins, 1994; Laurell & Hess, 1995; Laurell & others, 1993; Keen & others, 1994; Roeder & Berry, 1995; Brown & Barkmeier, 1996; Wu & others, 1983). Due to technological limitations and then available restorative materials, clinical use of air abrasion originally was limited to prophylaxis (Roeder & Berry, 1995; Berry & Ward, 1995). Advances in dental biomaterials and air-abrasion technology have encouraged reexamination of air abrasion as a potential alternative to acid etching (Myers, 1994; Goldstein & Parkins, 1994; Laurell, Lord & Beck, 1993). In fact various studies indicate that cavities prepared with air abrasion provide sufficient anchorage for bonding (Laurell, Lord & Beck, 1993; Keen & others, 1994) although other workers suggested that acid etching of the cavity was also necessary for adequate retention (Roeder & others, 1995; Brockmann & others, 1989; Brown & Barkmeier, 1996; Ploeger & others, 1996; Bae & others, 1996; Olsen & others, 1996).

Although many bond strength studies have been conducted, relatively few have reported on the microleakage behavior of teeth prepared by air abrasion, a question this study addressed. The electrochemical and silver staining findings presented here indicate that acid etched cavities, regardless of preparation technique, exhibited significantly less microleakage than those prepared by air abrasion only. Furthermore, there was a lower incidence of leakage to the pulpal floor with the two groups of acid etched cavities than with the air abraded tooth groups. Clearly, these findings support other reports which suggest that cavities prepared by air abrasion should also be acid etched to reduce susceptibility to microleakage (Laurell & Hess, 1995; Keen & others, 1994; Haws & others, 1996).

The differences in the microleakage behavior of acid etched and air abraded teeth may arise from the nature of the prepared tooth surface, that is, the air abraded cavity has a lower rugosity (approaching 50%) than that achieved with acid etching (Sheehan & others, 1996; Reisner, Levitt & Mante, 1997). The surface microtopography induced by acid etching extends the tooth structure/resin interface and thereby lengthens the leakage path so that microleakage is decreased.

Clinically, and in this study, both enamel and dentin are involved in the leakage behavior of restored teeth. Dentin bonding is more complex than enamel bonding and is markedly affected by the smear layer, the nature of the dentinal tubules and the degree of dentin sclerosis. The presence of a smear layer can inhibit penetration of bonding agents into the dentin substrate (Retief & Denys, 1989; Söderholm, 1995; Nikaido & others, 1995) and its removal, typically by acid etching, improves the bond strength to dentin. Air abraded dentin differs in appearance from mechanically prepared dentin, having an irregular surface with occluded tubules (Roeder & others, 1995; Amory & Yvon, 1994; Los & Barkmeier, 1994) that does not provide an adequate substrate for adhesion. Although it is well known that surface roughness increases with the abrasive particle diameter (Wolf, Powers & O'Keefe, 1993) and there appears to be an increase in bond strength when surfaces are abraded with larger diameter particles (Olsen & others, 1997), this and other studies in the literature showed no difference in microleakage (or bond strength) due to abrasive particle size effects (Keen & others, 1994; Roeder & others, 1995; Bae & others, 1996).

Although good correlation was found between the two microleakage test methods, differences were noted between the approaches. In particular, no difference

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($p>0.05$) was found between the cavities prepared by high speed and bur and the air abraded cavities with silver staining, but the difference was significant for the electrochemical test. The reason for this disparity is not clear but may originate from the marked differences in test methodology. The electrochemical technique is a continuous and stringent test that provides clearly defined parametric data. In contrast, evaluation of microleakage by silver nitrate staining relies upon observer evaluation and utilizes rank order data for statistical analysis. The silver nitrate microleakage stain test is commonly accepted (Wu & others, 1983; Dumsha & Biron, 1984; Hovland & Dumsha, 1985) and is discriminatory due to size differences between the silver ion (0.059 nm) and a typical bacterium (0.5-1 μm). Based on their relative sizes, any system that prevents the ingress of silver ions will also prevent the ingress of bacteria (Haws & others, (1996). Silver nitrate staining, however, is useful in characterizing the extent of microleakage and providing visible indication of microleakage around a restoration. Notwithstanding the usefulness of this visual evidence of microleakage, a disadvantage is that the specimens require sectioning and, therefore, only the microleakage within that particular plane is identified. Since the restoration/tooth interface is three-dimensional, relying upon a single or uniplanar measurement to characterize the overall leakage behavior of a restored tooth may be questionable.

CONCLUSIONS

This study has shown that surface treatment has a significant effect on microleakage between the tooth structure and the composite restoration. In particular, air abrasion alone does not induce sufficient surface roughening of hard tooth tissue to avoid or prevent microleakage. These findings indicate that hard dental tissues should always be acid etched prior to any bonding procedure irrespective of the cavity preparation method.

Two leakage regimens, electrochemical and silver nitrate staining, were investigated to optimize *in vitro* measurement and evaluate microleakage. The electrochemical technique provides a continuous evaluation of microleakage throughout the testing period but no data on the location of leakage. Conversely, the silver nitrate staining technique provides only one leakage value, namely that observed at the end of testing, but the test can provide information on the location of microleakage within the tooth/restoration interface. This is offset by the need to section specimens for examination and, generally, only microleakage within one plane can be identified.

Excellent correlation between the two microleakage test techniques was found. Teeth that showed high microleakage values with the electrochemical technique also presented deeper penetration of the silver ion into the tooth-restoration interface.

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Effect of Finishing and Polishing Procedures on the Surface Roughness of Packable Composites

LB Roeder • WH Tate • JM Powers

Clinical Relevance

Aluminum-oxide discs produced the smoothest surfaces as compared to five other finishing and polishing procedures for three packable and one hybrid composite restorative material.

SUMMARY

This study examined the average surface roughness (Ra, µm) of three packable composites and one hybrid composite cured against mylar, before and after treatment with a fine finishing diamond bur, a resin finisher followed by fine and extra-fine polishing paste, two silicone-based finishing and polishing systems, fine and super-fine aluminum-oxide polishing disks, a silicon carbide-impregnated polishing brush and a surface-penetrating composite sealant. Additionally, the Ra was examined for one of the packable composites before and after treatment with a finishing carbide, prior to the finishing and polishing procedures detailed above. The finishing diamond significantly increased the Ra for all composites (ALERT, SureFil, Solitaire and Z-100). The finishing carbide used with SureFil (SureFil+C) also increased the Ra; however, it also produced surfaces up to 3.5x smoother when compared to SureFil surfaces finished with the diamond. Overall, Sof-Lex Contouring and Polishing Discs were able to produce the smoothest surfaces, followed by the Jiffy Composite Polishing Cups, the Enhance Composite Finishing & Polishing System/Prisma-Gloss Composite Polishing Paste, the Diacomp Intra-Oral Composite Polishers and the Jiffy Composite Polishing Brushes, respectively. The smoothest surfaces were produced using Z-100, followed by SureFil+C (carbide finishing bur), Solitaire, SureFil and ALERT, respectively. In general, Protect-It Composite Surface Sealant had little effect on the Ra, except with ALERT, where a slight increase in Ra was observed.

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INTRODUCTION

The efficacy of finishing and polishing materials and procedures on contemporary composites is an important and often formidable challenge within the restorative process (Berastegui & others, 1992; Jefferies, Barkmeier & Gwinnett, 1992; Tate, DeSchepper & Cody, 1992; Tate & Powers, 1996). Restoration finish, surface roughness and surface integrity, as well as the physicochemical properties of the material itself, can affect plaque retention (Shintani & others, 1985; Toledano, de la Torre & Osorio, 1994; Weitman & Eames, 1975a; Weitman & Eames, 1975b), periodontal disease (Toledano & others, 1994) and recurrent decay (Toledano & others, 1994).

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Recently, various finishing and polishing systems and techniques have been examined using hybrid composite, micro-filled composite, glass-ionomer cement, resin-modified glass-ionomer and a compomer (Bouvier, Duprez & Lissac, 1997; Hoelscher & others, 1998; Hondrum & Fernández, 1997; Jung, 1997; Kaplan & others, 1996; McLean, Nicholson & Wilson, 1994; Tate, Goldschmidt & Powers, 1996; Tate & Powers, 1996; Yap, Lye & Sau, 1997).

Arising from the progressive development of composite restorative materials are the packable composite resins. These contemporary restorative materials contain various modified resin and filler systems. Manufacturers claim these materials have a clinical feel typical of amalgam, with amalgam-like condensability and physical properties that ensure their ability to hold shape and hold occlusal and interproximal anatomy and contour.

This study examined the effectiveness of various finishing and polishing procedures on three types of packable composites because there is no evidence to suggest which techniques or products are most effective on these new materials. The average surface roughness (Ra, µm) was evaluated for three packable and one conventional hybrid composite before and after sequential treatment with a fine finishing diamond, five finishing and polishing systems and a surface protecting sealant. One of the packable composites was further examined using a 12-fluted carbide-finishing bur for initial surface treatment, bringing the total number of techniques compared to six.

METHODS AND MATERIALS

Products, manufacturers and lot numbers of the restorative and finishing and polishing materials tested are listed in Table 1.

Three packable composites and one conventional hybrid composite were cured according to manufacturers' instructions with a curing light (The Max 100, Dentsply/Caulk, Milford, DE 19963) in acrylic wells (6 mm in diameter and 3 mm in depth) against a mylar strip/glass slide configuration. The curing light light-guide was placed perpendicular to the specimen surface, at or less than a distance of 1.0 mm. Curing light intensity was measured at 620 milliwatts per centimeter squared (mW/cm^2) and was monitored with a light meter (Tate, Porter & Dosch, 1999) (Cure Rite, Visible Curing Light Meter, Dentsply/Caulk, Milford, DE 19963). All specimens were light-cured for a total of 40 seconds. The mylar strip formed surface was used as baseline for all tests. Twenty-five specimens for each composite were fabricated and randomly divided among

Table 1: *Products, Lot Numbers and Manufacturers of Restorative and Finishing Materials Tested*

Composite (Shade)	Lot #	Manufacturer
• Restorative Z-100 (A3)	8WW	3M Dental Products St Paul, MN 55144
• ALERT Amalgam-Like Esthetic Restorative Treatment (B1)	196018	Jeneric/Pentron Wallingford, CT 06492
• Solitaire Polyglas Posterior Resin (A30)	32	Heraeus Kulzer, Inc Southbend, IN 46614
• SureFil High Density Posterior Restorative (A)	980622	Dentsply/Caulk Milford, DE 19963
Finishing Burs		
• H48L carbide (12-fluted)	279135	Brasseler USA Savannah, GA 31419
• 8862 012 finishing diamond (fine, 30 µm)	292524	Brasseler USA
Finishing and Polishing Systems		
• Diacomp Intra-Oral Composite Polishers		Brasseler USA
· Pre-Polish cups (green)	N/A*	
· High-Shine cups (grey)	N/A	
• Enhance Composite Finishing & Polishing System		Dentsply/Caulk
· Enhance finishing cups (resin)	9806122	
· Prisma-Gloss Composite Polishing Paste		
· fine (1.0 µm)	980319	
· extra-fine (0.3µm)	980205	
• Jiffy Composite Polishing Cups		Ultradent Products, Inc
· medium fine (yellow) (240 grit, 55µm)	2RFQ	South Jordan, UT 84095
· extra fine (white) (800 grit, 15µm)	2Q9R	
• Jiffy Composite Polishing Brush (4µm)	2RFT	Ultradent Products, Inc
• Sof-Lex Contouring and Polishing Disks		3M Dental Products
· fine (600 grit, 16-21µm)	H4441125632	
· super-fine (1200 grit, 2-5µm)	H4441126431	
Surface Sealant		
• Protect-It Composite Surface Sealant	840931	Jeneric/Pentron

*not available

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five treatment groups. Each treatment group was assigned to one of five finishing and polishing procedures (I-V).

Finishing and Polishing Procedure I (Enhance Cups)

Specimens were surfaced with a fine finishing diamond in a rotary motion to simulate initial finishing of the restorative material. They were then treated for 20 seconds with resin finishing cups impregnated with an abrasive (Enhance), followed by 10 seconds of polishing using fine polishing paste and 10 seconds of polishing using extra-fine polishing paste (Prisma-Gloss). Specimens were rinsed with water for 10 seconds and air dried for five seconds between and after polishing paste application. A composite surface sealant (Protect-It) was then applied according to manufacturer's directions.

Finishing and Polishing Procedure II (Diacomp Cups)

Specimens were surfaced with a fine finishing diamond. They were then treated for 20 seconds with pre-polish silicone-based finishing cups, followed by polishing for 20 seconds using high-shine silicone-based polishing cups (Diacomp). A composite surface sealant (Protect-It) was then applied according to manufacturer's directions.

Finishing and Polishing Procedure III (Sof-Lex Discs)

Specimens were surfaced with a fine finishing diamond. They were then treated for 20 seconds with fine aluminum-oxide (Al_2O_3) disks (Sof-Lex), followed by a 20-second treatment using super-fine Al_2O_3 disks (Sof-Lex). A composite surface sealant (Protect-It) was then applied according to manufacturer's directions.

Finishing and Polishing Procedure IV (Jiffy Cups)

Specimens were surfaced with a fine finishing diamond. They were then treated for 20 seconds with medium fine silicone-based abrasive cups, followed by a 20-second treatment using extra-fine silicone-based abrasive cups (Jiffy Cups). A composite surface sealant (Protect-It) was then applied according to manufacturer's directions.

Finishing and Polishing Procedure V (Jiffy Brush)

Specimens were surfaced with a fine finishing diamond. They were then treated for 40 seconds with an abrasive polishing brush impregnated with silicon carbide particles (Jiffy Brush). A composite surface sealant (Protect-It) was then applied according to manufacturer's directions.

Twenty-five additional specimens were fabricated using SureFil restorative material. Following the manufacturers' recommendation, a 12-fluted carbide finishing bur was used for the initial finishing of these specimens (SureFil+C). Finishing and Polishing Procedures I-V were then followed as described above.

All finishing and polishing steps were performed dry by a single operator using a low-speed handpiece running at approximately 4000-5000 RPM for clinical relevance (Briseño, Ernst & Willershausen-Zönnchen, 1995). After each treatment step, average surface roughness (Ra) measurements were taken using a surface profilometer (Talysurf 10, Taylor-Hobson, Leicester, England) set for a tracing length of 2 mm and a cutoff value of 0.25 mm to maximize surface waviness filtration (Bessing & Wiktorsson, 1983). Five tracings were performed at different locations on each of the specimen surfaces. Representative specimens from various treatment steps were examined by scanning electron microscopy (SEM)(JSM-820, JEOL, USA, Inc, Peabody, MA 01960).

Mean values and standard deviations of Ra were determined. The data were analyzed by analysis of variance (SuperANOVA, Abacus Concepts, Inc, Berkeley, CA 94704). Tukey-Kramer intervals (SuperANOVA) at a 0.05 significance level for comparisons among surface treatments and products were determined.

RESULTS

Means and standard deviations of surface roughness (Ra, μm) are listed in Tables 2 and 3, and graphically depicted in Figures 1 through 6. Electron micrographs (SEM) are pictured in Figures 7 through 10. Overall, the smoothest initial surfaces created against a mylar strip were attained with Z-100. ALERT had the roughest initial surfaces. The greatest variability in initial surface roughness between groups was also observed with ALERT. The finishing diamond roughened all surfaces from seven to sixty-fold when compared to baseline. The finishing carbides used with the SureFil+C groups roughened the surfaces from three to nine-fold.

Finishing and Polishing Procedure I (Enhance Cups)

The Enhance cups (Table 2, Figure 1) reduced the surface roughness (Ra) of the finishing diamond treated Z-100 surfaces by 4x, the Solitaire surfaces by 3.7x, the SureFil surfaces by 2.9x and the ALERT surfaces by 1.8x. The application of Protect-It significantly increased the Ra values for SureFil and ALERT. Protect-It had no significant effect on the Ra of Solitaire and Z-100.

For the SureFil+C group (Table 3), the Enhance cups significantly roughened the finishing carbide treated (SureFil+C) surfaces. When compared to the finishing diamond/Enhance cup treated SureFil surfaces, the Enhance cup treated SureFil+C surfaces were also significantly rougher. The application of Protect-It significantly increased the surface smoothness of the

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Table 2: *Effect of Finishing and Polishing Treatments on Surface Roughness (Ra, µm) of Condensable and Hybrid Composites*

	ALERT	SureFil	Solitaire	Z-100
Procedure I*				
Baseline	0.07 (0.05)	0.06 (0.04)	0.04 (0.02)	0.03 (0.01)
Diamond	1.60 (0.40)	1.50 (0.30)	1.70 (0.20)	1.70 (0.40)
Enhance Cup†	0.87 (0.28)	0.52 (0.16)	0.46 (0.16)	0.42 (0.10)
Protect-It	1.00 (0.30)	0.59 (0.12)	0.52 (0.15)	0.43 (0.10)
Procedure II*				
Baseline	0.22 (0.14)	0.06 (0.03)	0.04 (0.02)	0.03 (0.02)
Diamond	1.50 (0.50)	1.40 (0.30)	2.20 (0.40)	1.20 (0.50)
Diacomp Cup	0.79 (0.31)	0.59 (0.20)	0.91 (0.27)	0.44 (0.12)
Protect-It	0.90 (0.20)	0.56 (0.16)	0.71 (0.19)	0.42 (0.19)
Procedure III*				
Baseline	0.15 (0.13)	0.06 (0.03)	0.04 (0.02)	0.04 (0.02)
Diamond	1.10 (0.30)	1.40 (0.40)	1.50 (0.30)	1.60 (0.50)
Sof-Lex Discs	0.39 (0.13)	0.24 (0.08)	0.20 (0.10)	0.16 (0.12)
Protect-It	0.45 (0.12)	0.24 (0.09)	0.21 (0.10)	0.17 (0.12)
Procedure IV*				
Baseline	0.11 (0.08)	0.04 (0.02)	0.04 (0.02)	0.04 (0.02)
Diamond	2.10 (0.50)	1.30 (0.30)	1.90 (0.40)	1.70 (0.30)
Jiffy Cup	1.70 (0.40)	0.34 (0.11)	0.23 (0.05)	0.21 (0.03)
Protect-It	1.70 (0.30)	0.36 (0.09)	0.21 (0.05)	0.23 (0.04)
Procedure V*				
Baseline	0.11 (0.11)	0.05 (0.02)	0.04 (0.02)	0.03 (0.01)
Diamond	1.40 (0.20)	1.60 (0.30)	1.70 (0.40)	1.80 (0.40)
Jiffy Brush	0.79 (0.20)	0.90 (0.38)	0.96 (0.34)	1.20 (0.40)
Protect-It	0.91 (0.26)	1.10 (0.30)	0.91 (0.29)	1.10 (0.40)

*Surface roughness (n = 25) with standard deviations in parentheses are listed in µm. Data were analyzed by ANOVA. Tukey-Kramer intervals at a 0.05 significance level for comparisons among products and techniques were 0.04µm and 0.05µm, respectfully.
†Enhance cup followed by Prisma-Gloss.

SureFil+C, Enhance treated surfaces, producing a surface which was also significantly smoother than the Protect-It treated finishing diamond/Enhance cup treated SureFil surfaces.

Finishing and Polishing Procedure II (Diacomp Cups)

The Diacomp cups (Table 2, Figure 2) reduced the Ra of the finishing diamond treated Z-100 surfaces by 2.7x, the Solitaire surfaces by 2.4x, the SureFil surfaces by 2.4x and the ALERT surfaces by 1.9x. Protect-It application significantly decreased the Ra for Solitaire, did not affect SureFil and Z-100 and increased the Ra for ALERT.

The Ra of the SureFil+C surfaces (Table 3) was reduced by 1.2x using the Diacomp cups. These surfaces were also significantly smoother compared to the finishing diamond/Diacomp cup treated SureFil surfaces. The application of Protect-It had no significant effect on the Ra for the SureFil+C, Diacomp finished surfaces; however, they were significantly smoother when compared to the Protect-It treated surfaces of the finishing diamond/Diacomp cup treated surfaces.

Finishing and Polishing Procedure III (Sof-Lex Discs)

The Soft-Lex Discs (Table 2, Figure 3) reduced the Ra of the finishing diamond treated Z-100 surfaces by 10x, the Solitaire surfaces by 7.5x, the SureFil surfaces by 5.8x and the ALERT surfaces by 2.8x. The Protect-It application had no significant effect on the Ra.

The Ra of the SureFil+C surfaces (Table 3) was reduced by 3.6x using the Sof-Lex disks. These surfaces were also significantly smoother in comparison to the finishing diamond/Sof-Lex disk treated SureFil surfaces. The application of Protect-It had no significant effect on Ra for either comparison.

Finishing and Polishing Procedure IV (Jiffy Cup)

The Jiffy Cups (Table 2, Figure 4) reduced the Ra of the finishing diamond treated Z-100 surfaces by 8.1x, the Solitaire surfaces by 8.3x, the SureFil surfaces by 3.8x and the ALERT surfaces by 1.2x. The Protect-It application had no significant effect on Ra.

The Ra of the SureFil+C surfaces (Table 3) was reduced by 1.3x using the Jiffy cups. When compared to the finishing diamond/Jiffy cup treated SureFil surfaces, there was no significant difference in Ra. The application of Protect-It significantly increased the Ra of the SureFil+C, Jiffy cup treated surfaces, which was also significantly rougher than the Ra of the Protect-It treated finishing diamond/Jiffy cup treated SureFil surfaces.

Finishing and Polishing Procedure V (Jiffy Brush)

The Jiffy Brushes (Table 2, Figure 5) reduced the Ra of the finishing diamond treated Z-100 surfaces by 1.5x, the Solitaire surfaces by 1.8, the SureFil surfaces by 1.8x and the ALERT surfaces by 1.8x. The Protect-It application created a significantly rougher surface for the SureFil, and ALERT groups and smoother surfaces for Z-100. It had no significant effect on the Solitaire surfaces.

The Ra of the SureFil+C surfaces (Table 3) was reduced by 1.8x using the Jiffy Brush. The SureFil+C, Jiffy Brush treated group, produced significantly smoother surfaces when compared to the finishing diamond/Jiffy Brush treated groups, regardless of composite.

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Table 3: *Comparison of Finishing and Polishing Treatments on Surface Roughness (Ra, µm) of SureFil after Initial Finishing with Finishing Carbides and Finishing Diamonds*

	SureFil	SureFil+C
Procedure I*		
Baseline	0.06 (0.04)	0.06 (0.03)
Bur†	1.50 (0.30)	0.48 (0.15)
Enhance Cup‡	0.52 (0.16)	0.59 (0.18)
Protect-It	0.59 (0.12)	0.46 (0.16)
Procedure II*		
Baseline	0.06 (0.03)	0.09 (0.06)
Bur†	1.40 (0.30)	0.52 (0.11)
Diacomp Cup	0.59 (0.20)	0.42 (0.13)
Protect-It	0.56 (0.16)	0.39 (0.08)
Procedure III*		
Baseline	0.06 (0.03)	0.07 (0.05)
Bur†	1.40 (0.40)	0.61 (0.10)
Sof-Lex Discs	0.24 (0.08)	0.17 (0.06)
Protect-It	0.24 (0.09)	0.21 (0.09)
Procedure IV*		
Baseline	0.04 (0.02)	0.14 (0.09)
Bur†	1.30 (0.30)	0.37 (0.12)
Jiffy Cup	0.34 (0.11)	0.28 (0.12)
Protect-It	0.36 (0.09)	0.46 (0.14)
Procedure V*		
Baseline	0.05 (0.02)	0.08 (0.04)
Bur†	1.60 (0.30)	0.52 (0.17)
Jiffy Brush	0.90 (0.38)	0.29 (0.08)
Protect-It	1.10 (0.30)	0.32 (0.10)

*Surface roughness (n = 25) with standard deviations in parentheses are listed in µm. Data were analyzed by ANOVA. Tukey-Kramer intervals at a 0.05 significance level for comparisons among products and techniques were 0.03 µm and 0.06 µm, respectively.
†Finishing diamond (SureFil) or finishing carbide (Surefil+C)
‡Enhance cup followed by Prisma-Gloss.

The application of Protect-it had no significant effect on the Ra; however, when compared to the finishing diamond/Jiffy Brush treated SureFil surfaces treated with Protect-It, the surfaces were significantly smoother.

DISCUSSION

The effectiveness of finishing and polishing procedures on contemporary composite surfaces is an important consideration in the restorative process. This study, as well as others (Chung, 1994; Hondrum & Fernandez, 1997; Yap & others, 1997), found that the mylar strip-formed surface was the smoothest composite surface produced. The surface roughness (Ra, µm) of the mylar-formed surface was significantly increased by the use of finishing diamonds. With hybrid composites, finishing diamonds have been shown to produce rough, trough-like surfaces compared to carbide burs (Jung, 1997). Jung suggested that finishing diamonds were best suited for gross removal and contouring due to their high cutting efficiency of composite surfaces, while carbide finishing burs would be best suited for smoothing and finishing as a result of their low cutting efficiency. Another study also found that finishing diamonds were more efficient in removing material from the composite surface, though they tended to leave a more irregular surface when compared to a finishing carbide (Ferracane, Condon & Mitchem, 1992). Others suggest that both diamond and carbide finishing burs should be used not as instruments for finishing and polishing, but instead as instruments for initial modeling of the restoration (Berastegui & others, 1992).

In this study carbide finishing burs, used with SureFil (SureFil+C) in accordance with manufacturer's recommendations, produced surfaces with Ra values (Table 3) that averaged three times as smooth when compared to SureFil surfaced with finishing diamonds. Troughs, produced by a finishing diamond within SureFil, appear more excessive when compared to a carbide finished SureFil surface (Figures 7-8). All finishing and polishing procedures produced final surfaces with a lower Ra when finishing carbide burs were used for initial surfacing when compared to initial SureFil surfacing with finishing diamonds. Overall, SureFil finished with carbide burs were smoother than all composite surfaces finished with finishing diamonds. Conversely, Kaplan & others (1996), using hybrid composites, observed that diamonds caused a greater degree of gouging; however, the gouges were not as deep as those produced with carbides and, therefore, could be brought to a smoother polish. In this study, when comparing all composites except for Z-100, finishing and polishing procedures produced smoother final surfaces for SureFil when carbide-finishing burs were used for initial surfacing. It is also interesting to note that subsurface damage due to the use of a carbide bur or finishing diamond during the initial contouring of a restoration was not found to be significantly different for both a micro-fill and hybrid composite (Ferracane & others, 1992).

Overall, Sof-Lex Contouring and Polishing Discs produced the smoothest finished surfaces followed by the Jiffy Composite Polishing Cups, the Enhance Composite Finishing & Polishing System/Prisma-Gloss Composite Polishing Paste, the Diacomp Intra-Oral Composite Polishers and the Jiffy Composite Polishing Brushes, respectively (Table 2, Figure 6). Other studies have also shown the ability of aluminum oxide disks to produce smooth composite surfaces (Berastegui & others, 1992; St Germain & Meiers, 1996; Setcos, Tarim & Suzuki, 1999; Tate & Powers, 1996; Toledano & others, 1994). An earlier study showed that the capability of aluminum oxide disks to produce smooth surfaces was related to their ability to cut the filler particle and matrix equally (van Dijken & Ruyter, 1987). The planar motion of the disc may also contribute to the smoother surface (Fruits, Miranka & Coury, 1996). Disadvantages of aluminum oxide disks are limitations due to geometry. Using the disks, it is often difficult to efficiently create, finish and anatomically polish contoured surfaces, especially in the posterior regions of the mouth. Overall, other fin-

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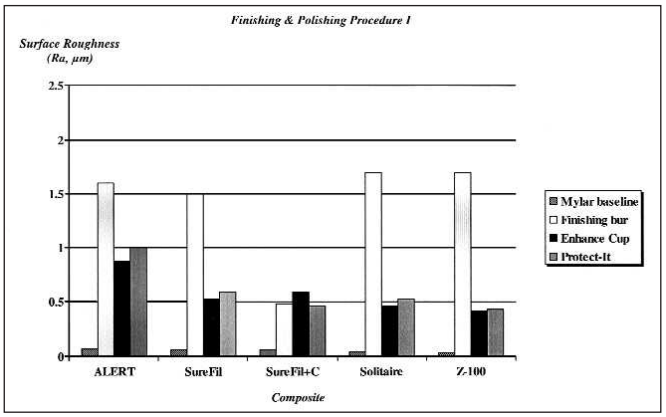

Figure 1. *Effect of Finishing and Polishing Procedure I (Enhance) on surface roughness (Ra, µm) of three condensable and one hybrid composite; Enhance cups = Enhance Cups/Prisma-Gloss Polishing Paste.*

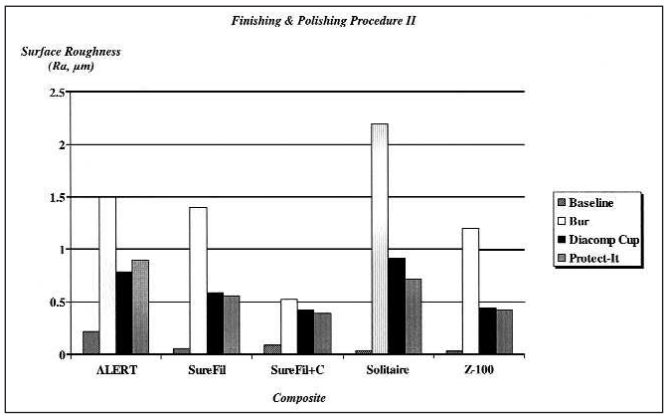

Figure 2. *Effect of Finishing and Polishing Procedure II (Diacomp) on surface roughness (Ra, µm) of three condensable and one hybrid composite.*

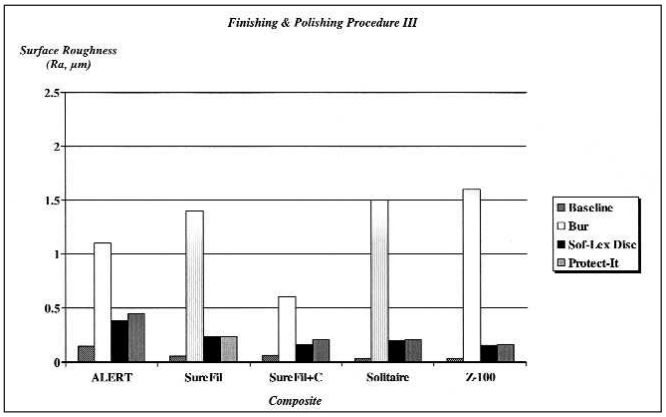

Figure 3. *Effect of Finishing and Polishing Procedure III (Sof-Lex) on surface roughness (Ra, µm) of three condensable and one hybrid composite.*

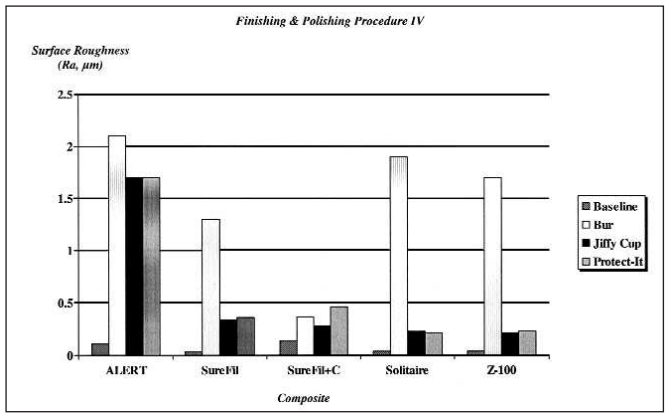

Figure 4. *Effect of Finishing and Polishing Procedure IV (Jiffy Cups) on surface roughness (Ra, µm) of three condensable and one hybrid composite.*

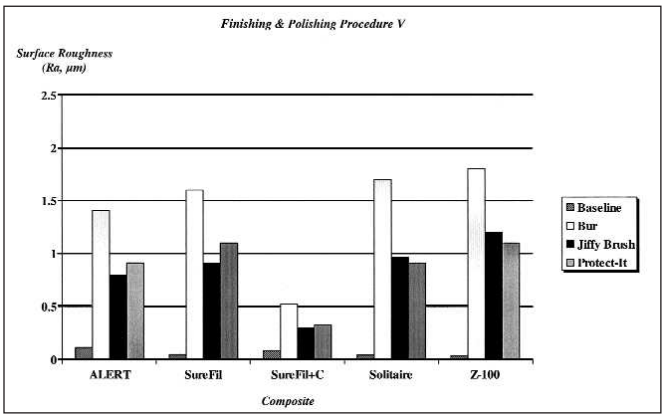

Figure 5. *Effect of Finishing and Polishing Procedure V (Jiffy Brush) on surface roughness (Ra, µm) of three condensable and one hybrid composite.*

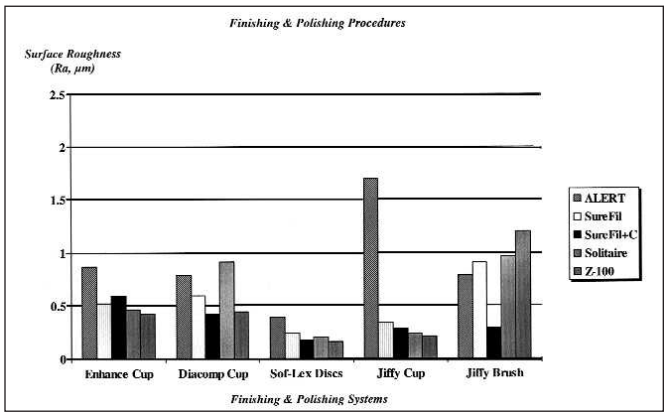

Figure 6. *Effect of Finishing and Polishing Procedures on surface roughness (Ra, µm) of three condensable and one hybrid composite prior to surface sealant application.*

ishing and polishing systems with instruments of varied shapes may lend themselves in many clinical situations to more efficient and consistent composite finishing.

Studies have reported no appreciable difference in plaque accumulation between surfaces polished by different methods that resulted in Ra values within a 0.7-

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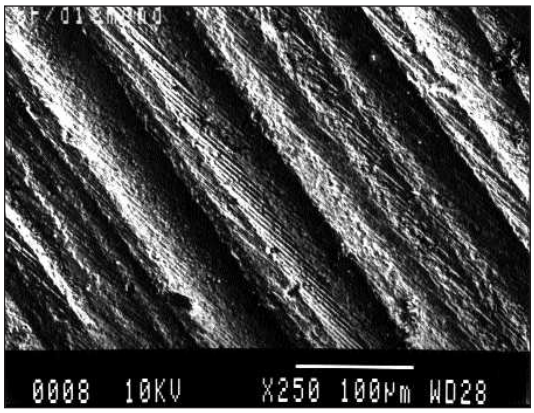

Figure 7. *SEM of the SureFil surface after finishing with a finishing diamond bur (250X).*

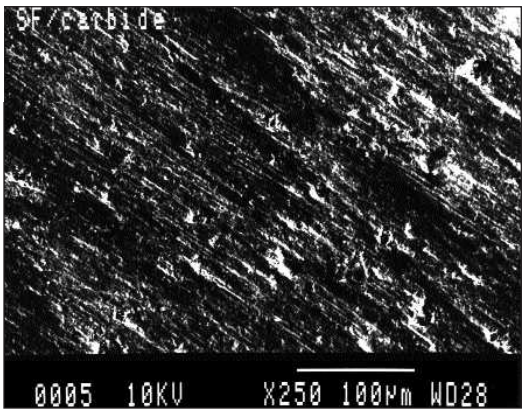

Figure 8. *SEM of the SureFil surface after finishing with a finishing carbide bur (250X).*

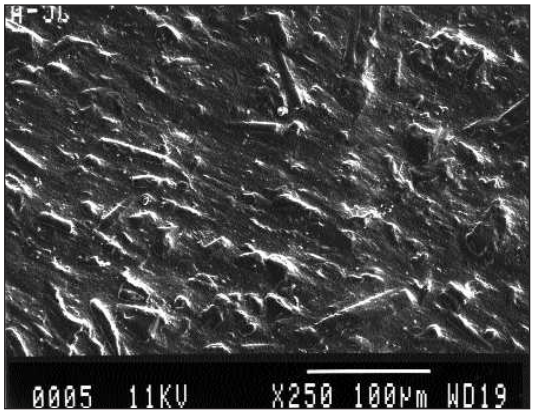

Figure 9. *SEM of the ALERT surface after finishing with Jiffy Cups (250X).*

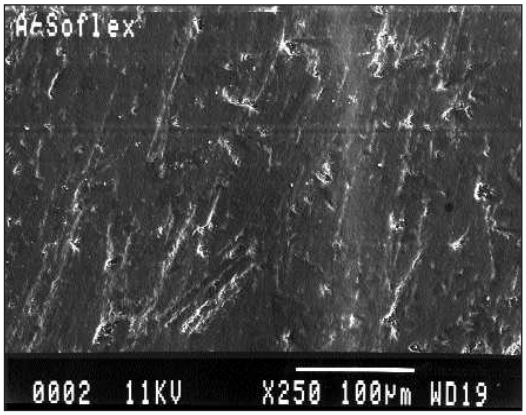

Figure 10. *SEM of the ALERT surface after finishing with Sof-Lex discs (250X).*

1.4 µm range (Shintani & others, 1985; Weitman & Eames, 1975a; Weitman & Eames, 1975b). Most finishing and polishing systems used in this study produced a Ra below 0.7 µm for the composites tested, the exceptions being Diacomp used with Solitaire and ALERT, Enhance and Jiffy Cup used with ALERT and the Jiffy Brush used with all composites that were initially treated with the finishing diamond. Studies examining the relation between the Ra of titanium implants and bacterial adhesion found that a further reduction in Ra below a threshold level of 0.2 µm, had no effect on supra- and subgingival micro-biological adhesion or colonization (Bollen & others, 1996; Quirynen & others, 1996). In this study, excluding the mylar formed surfaces, only Sof-Lex disks used with Solitaire, Z-100, and SureFil finished with a finishing carbide bur were able to produce Ra values at 0.2 µm or less. Jiffy brushes produced the highest Ra values for all composites when compared to the other finishing and polishing systems, except for SureFil finished with a carbide-finishing bur. Here, finished surfaces were comparable to surfaces finished with the other systems. As one might expect, the brushes with their smaller particle size (4 µm), were unable to adequately abrade, remove and finish areas of material within the filler phase damaged by the diamond bur. Perhaps by restricting the initial surface finishing to carbide finishing burs or by using these brushes in sequence with the Jiffy Cups, which contain larger particles (15 µm and 55 µm), the overall efficacy and usefulness of these brushes would increase significantly.

The smoothest composite surfaces were produced using Z-100, followed by SureFil+C, Solitaire, SureFil and ALERT, respectively. Composite resin fillers appear to play an intrinsic role in how well a composite finishes (Berastegui & others, 1992; Strassler, 1992; Toledano & others, 1994; Yap & others, 1997). In composites where the filler particles are significantly harder than the matrix, the resin phase may suffer a preferential loss during finishing and polishing. This will result in the filler phase showing in positive relief on the surface (Chung, 1994; Toledano & others, 1994; Yap, 1997). The larger the filler particle sizes, the greater the surface roughness (Toledano & others, 1994; Yap, 1997). As mentioned previously, the ability of the polishing procedures to abrade the filler phase has been shown to influence the surface roughness (Yap, 1997).

These new composites, although similarly marketed for their packability, are manufactured with very different filler particles. The filler phase of ALERT consists of traditionally cut particles, colloidal silica and silanated, chopped glass fibers. The conventional filler particle size ranges from 0.01 to 3.0 µm, averaging 0.7 µm. The glass fibers average 40 mm. The filler particles of ALERT range from 1.0 to 110 µm (Tabassian & Moon, 1999). ALERT is filled 70% by volume (Farah & Powers, 1998). Regardless of the finishing and polishing procedure, the final overall Ra values for ALERT were higher than for all of the other composites tested in this study. A highly textured ALERT surface after Jiffy Cup fin-

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ishing can be seen in Figure 9. Exceptions to these findings were surfaces finished with Jiffy Brushes. Here, the final Ra for ALERT was lower when compared to SureFil, Solitaire and Z-100, albeit almost five times the Ra of the smoothest final surface obtained in the study. ALERT contained the largest filler particles of the composites examined. These observations coincide with the findings that the larger the filler particle size, the greater the resulting Ra value (Toledano & others, 1994; Yap, 1997). Overall, Sof-Lex discs produced the smoothest ALERT surfaces as evidenced by Figure 10.

SureFil has an average particle size of 0.8 μm, with the largest particles at 6 μm (as reported by the manufacturer). Tabassian & Moon (1999) described filler particles of SureFil as ranging from 1.0 to 20 μm. The filler content is 66% by volume (Farah & Powers, 1998) and is composed of barium fluro alumino borosilicate glasses and fumed silica. According to the company, the packability is achieved by using four distinct particle size distributions and morphologies. Under these conditions, the resin matrix is minimized and the filler component is maximized (Leinfelder, 1998). Decreased matrix volume would reduce the preferential loss of the resin phase during finishing and polishing, thereby reducing areas of filler showing positive relief. However, a decreased matrix volume may contribute to dislodgment of the larger filler particle during the finishing and polishing procedures due to an inability to adequately stabilize these particles, thus increasing the Ra values.

Solitaire is characterized by the manufacturer as having a variable filler particle size of 2-20 μm and is 66% filled by volume (Farah & Powers, 1998). Others have reported Solitaire's filler particle size to be between 0.5 and 11 μm (Tabassian & Moon, 1999). Filler particles consist of silica dioxide, barium aluminum boroflurosilicate glass and aluminum fluroride glass according. Solitaire does not contain BISGMA (biphenol glycidyl methacrylate) or TEG-DMA (tetraethylene glycol dimethacrylate) resins, instead its matrix chemistry is described by the manufacturer as being composed of a "vitroid polyglas monomer, an indirect high heat and pressure-cured polycarbonate vitroid glass ceramic material." Each filler particle is covered or coated with small nodules. These surface bumps prevent the free flowing of one particle past another when subjected to condensing forces. This type of physical interaction between the particles imparts condensable, packable characteristics (Leinfelder, 1998). This surface topography may also prevent the filler particles from dislodging when subjected to occlusal loading and may also help prevent particle dislodgment or "plucking" during finishing and polishing procedures (Leinfelder, 1998), resulting in lower Ra values.

Z-100, a hybrid composite, contains zirconia/silica filler particles which range in size from 0.01–3.5 μm, averaging 0.6 μm. It is 66% filled by volume. This material finished to the lowest Ra values for all of the finishing and polishing procedures except when finished with Jiffy Brushes. The smaller filler particle sizes account for its increased polishability and lower Ra values (Toledano, 1994; Yap, 1997); however, the brushes were not as efficient at abrading and finishing the zirconia/silica filler particles.

In general, Protect-It Composite Surface Sealant had little effect on Ra values except for a slight increase observed with ALERT. Rebonding of composite restorations with unfilled resin has been recommended for penetration of the subsurface micro-cracks and interfacial gaps generated during finishing and polishing procedures as well as decreasing wear (Dickinson & Leinfelder, 1993; Schwartz, Summitt, Robbins, 1996). May & others (1996) reported that with four different restorative systems, microleakage at enamel margins was minimal regardless of whether a resin sealant was used; therefore, rebonding did not improve the restorations' performance. However, they also stressed that the results of this *in vitro* study might not predict the clinical effectiveness of a surface sealant in reducing marginal leakage (May & others, 1996). Further, the durability and long-term value of these resins has yet to be fully clarified (Hondrum & Fernández, 1997).

In this study surface sealing with Protect-It after finishing and polishing procedures had little effect on the surface roughness. Composite surfaces should, therefore, be completely contoured, finished and polished before surface sealing, as the surface sealant will not adequately compensate for surface irregularities produced by finishing and polishing instruments. In addition, the surface sealant appeared to "bead" and not readily penetrate the composite surfaces finished with Jiffy Cups. The rubber-based cups may degrade and alter the surface properties of the composite, thereby affecting the wettability of the surface. Furthermore, a rubber-based smear layer may be produced that inhibits the penetration of the low-viscosity resin.

Lastly, what effect, if any, various finishing and polishing procedures and systems have on adjacent natural tooth structure would be an appropriate area for future studies. The potential for iatrogenic alteration of natural tooth structure when utilizing these systems would certainly be relative information when considering the selection of finishing and polishing instruments.

CONCLUSIONS

Overall, Sof-Lex Contouring and Polishing Discs produced the smoothest surfaces, followed by the Jiffy Composite Polishing Cups, the Enhance Composite Finishing & Polishing System/Prisma-Gloss

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Composite Polishing Paste, the Diacomp Intra-Oral Composite Polishers and the Jiffy Composite Polishing Brushes, respectively. The smoothest surfaces were produced using Z-100, followed by SureFil+C, Solitaire, SureFil and ALERT, respectively. In general, Protect-It Composite Surface Sealant had little effect on the Ra, except with ALERT, where a slight increase in Ra was observed.

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Handpiece Coolant Flow Rates and Dental Cutting

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Clinical Relevance

Increasing the coolant flow rate during tooth preparation procedures should maximize cutting efficiency and result in improved practice efficiency.

SUMMARY

High-speed handpieces incorporate water coolant sprays to remove cutting debris and minimize thermal insult to the pulp. Little data exists on optimal coolant flow rates during clinical procedures. This study compared the effect of different coolant flow rates on diamond stone cutting efficiency.

Cutting studies were performed on Macor machinable ceramic using a previously developed test regimen—a KaVo high-speed handpiece at a cutting force of 91.5 g (0.9N). Cutting was performed with round end tapered medium grit diamond stones under cooling water flow rates of 15, 20, 25, 30 and 44 ml/min, with cutting rates determined as the time to transect the 13 mm square cross-section of the Macor bar. Each bur was used for five cuts, with six burs used for each flow rate, for a total of 150 measurements. The data were analyzed by one-way ANOVA with a post hoc Scheffé test.

The cutting studies indicated that diamond stone cutting rates increased with higher coolant flow rates over the range of 15-44 ml/min. The data suggest that higher coolant flow rates promote cutting efficiency.

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INTRODUCTION

It is well established that water coolant sprays directed at the bur/tooth interface reduce the risk of thermal damage to the dental pulp during cutting procedures. Little data exist on the optimum coolant flow rates for dental cutting and little information is evident in either dental or engineering literature on the effect of coolant flow rates on cutting efficiency. Minimizing thermal damage to the dental pulp during restorative procedures is a principle accepted by dentists since the classic work of Stanley (Stanley & Swerdlow, 1959; Stanley, 1961), Zach and Cohen (1965), Langeland (1972) and Schuchard (1979). The superior cooling achieved with water spray compared to air cooling during cutting has been established in numerous studies (Stanley & Swerdlow, 1959; Stanley, 1961; Schuchard, 1979; Peyton, 1952; Holland & others, 1972; Wittrock, Morrant & Davies, 1975; Baum, Phillips & Lund, 1985; van Amerongen & Penning, 1990; Laforgia & others, 1991) and the use of water coolants is advocated in dental

textbooks (Baum, Phillips & Lund, 1995; Rosenstiel, Land & Fujimoto, 1995; Shillingburg & others, 1997). The majority of cutting studies cite using water coolants but, like dental textbooks, most do not provide information on the optimal flow rate of the water coolant (Dyson & Darvell, 1995).

A recent survey (Siegel and von Fraunhofer, 1999) of certain aspects of North American Dental School clinical teaching indicated that 79% (46 out of 58 schools) make no recommendations on coolant flow rates for students. Of the 12 schools making recommendations on coolant flow, five advocated flow rates of 10 ml/min or less, while the other seven recommended rates of 30 ml/min or greater. In contrast, it appears that dental schools in Austria, Germany and Switzerland advocate markedly higher coolant flow rates (Kimmel, 1993a; Kimmel, 1995; Kimmel 1993b). When asked about this issue, handpiece manufacturers advise dentists to use flow rates that they are comfortable with instead of offering suggestions. Clearly, water coolant flow rates for dental handpieces is a vague area in clinical practice and the literature provides little guidance.

One early cutting study (Stanley & Swerdlow, 1959) reported water flow rates of 22 ml/min with low speed handpieces (6000 and 20,000 rpm), 18 ml/min with a belt-driven high speed (150,000 rpm) and 35 ml/min with an air turbine (200,000 rpm). In two studies comparing pulpal effects with water and air cooling of high-speed (250,000 rpm) handpieces, one paper cited a water flow rate of 30 ml/min (Dachi & Stigers, 1968), while the other used an air-water spray at approximately 0.35 ml/min (Schuchard, 1979). Interestingly, both studies reported that when used judiciously, minimal differences in histological changes were found with air cooling compared to water cooling. In contrast, a study comparing temperature elevation in the pulp during crown preparation with diamond stones under air cooling and water spray showed that water cooling was far more effective (Laforgia & others, 1991). In the latter study, a water coolant flow rate of 4.16 ml/min was used with an air turbine operating at 250,000 rpm.

Previous cutting studies within this laboratory were performed at coolant flow rates of 15-20 ml/min (Siegel and von Fraunhofer, 1996, 1997, 1999a), which are typical flow rates used by US dentists (Norling & Stanford, 1976; von Fraunhofer, Givens & Overmyer, 1989). This study compared the effect of coolant flow rate on diamond stone cutting efficiency. The underlying hypothesis of the study was that increased rates of coolant flow at the bur/workpiece interface should result in faster cutting rates.

METHODS AND MATERIALS

A pilot study established a baseline of the preferred coolant flow rates for the proposed cutting study. A random sampling of 10 full-time dental faculty and 10 final year (senior) dental students were asked to adjust the handpiece coolant flow rate to their preferred setting. The coolant delivery rate was measured with a graduated cylinder for one minute and three determinations of the flow rate were made for each operator. Mean values (and their standard deviations) were calculated for coolant flow rates for the faculty and student test groups.

A previously developed test regimen for dental cutting was used in this study (Siegel and von Fraunhofer, 1996, 1997). A KaVo 640B super-torque high-speed handpiece (KaVo America Corp, Lake Zurich, IL) was mounted within a frictionless bearing attached to an acrylic framework. The handpiece was loaded such that there was a force of 91.5 g (0.9N) at the contact interface between the stone and the cutting substrate. All cutting studies were performed on an enamel substitute, namely a 13 mm square cross-section Macor bar, Macor being a machinable glass ceramic with the composition 55% fluorophlogopite mica and 45% borosilicate glass (Corning Glass Works, Corning, NY). Round-end tapered medium-grit diamond (ISO 856-016) stones (Patriot diamond burs, KRI Corp, Romulus, MI) were used for cutting. Coolant water flow rates of 15, 20, 25, 30 and 44 ml/min were used, 44 ml/min being the maximum output for the test unit. The flow rates were determined by adjusting the water control valve on the test unit and measuring the amount of water (±1 ml) delivered via the handpiece spray ports in one minute with a graduated cylinder. Three determinations were made of the water delivery rate for each experimental coolant flow rate before each series of cuts.

Cutting rates (CR) were determined by measuring the time (± 0.01 min) to transect the 13 mm thick bar, each stone being used for five cuts. Six stones were used for each of the coolant flow rates so that 30 cutting rate determinations were made for each flow rate. The data were analyzed by one-way ANOVA with a post hoc Scheffé test at an a priori α=0.05.

The stones, following Macor cutting, were examined at 25X magnification under a stereoscopic light microscope (Stereomaster Zoom Microscope, Carton Optical Int, Tokyo, Japan) to evaluate the degree of debris accumulation. The tested stones were compared with new samples of the stones.

RESULTS

Table 1 shows coolant flow rates measured for senior dental students and experienced dental teaching faculty. The data indicate that experienced dentists use a mean flow rate of 14 ml/min, similar to those typical of US dentists. It should be noted, however, that the data had an enormous (97%) variability. While the variability in dental student flow rates was lower (70%), their water

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coolant flows rates were approximately 1/3rd that of experienced dentists ($p<0.05$).

Table 2 and Figure 1 show the cutting rates of Macor in mm/s at coolant flows of 15, 20, 25, 30 and 44 ml/min. Statistical analyses of the data are summarized in Table 3. No difference ($p>0.05$) was found in the cutting rate (CR) between flow rates of 15 and 20 ml/min; however at 25 ml/min, there was an 80% increase in CR ($p<0.05$) and a 160% increase at a flow rate of 30 ml/min ($p<0.05$). When the water flow rate was increased to 44 ml/min, the maximum flow rate of the unit, the cutting rate increase, compared to 15 ml/min, was 215% ($p<0.05$). However, no significant difference ($p>0.05$) in CR values existed between 30 and 44 ml/min.

Table 1: *Coolant Flow Rates (ml/min) for Senior Dental Students and Experienced Dentists*

	Dental Students	Experienced Dentists
Range	1-15	1-52
Mean	5.3	14.1
Standard Deviation	3.7	13.7
Coefficient of Variation	69.8	97.3

Table 2: *Macor Cutting Rates for Different Coolant Flow Rates*

Coolant Flow Rate (ml/min)	Cutting Rate (mm/s)	Increase in CR ** (%)
15	0.20 ±0.02*	--
20	0.19 ±0.02	-5
25	0.36 ±0.06	80
30	0.52 ±0.11	160
44	0.63 ±0.09	215

*: Mean value ± standard deviation
**: Cutting rate compared to initial cutting rate at a coolant flow rate of 15 ml/min.

Table 3: *Statistical Comparison of Cutting Rates*

Coolant Flow Rate	15	20	25	30	44
15	--	nS	S	S	S
20		--	S	S	S
25			--	S	S
30				--	nS

nS: non-significant difference ($p>0.05$); S: significant difference ($p0.05$).

Microscopic examination of the stones following the total cutting regimen showed a build-up of debris during cutting. However, no differences in the amount of debris accumulation could be discerned on the stones used at the five water coolant flow rates.

A post hoc power analysis of the test regimen showed that for the selected sample size, a mean difference of 1.26 ml/min could be detected at a power of 0.83 for $\alpha=0.05$.

DISCUSSION

The literature (Siegel and von Fraunhofer, 1996, 1997, 2000; Norling & Stanford, 1976; von Fraunhofer & others, 1989) and the limited survey reported here suggest that a coolant flow rate of approximately 15 ml/min is the norm for experienced dentists. The lower water flow rates (1-15 ml/min with a mean of 5.3 ml/min) used by dental students might be expected from the commonly stated student complaint that high flow rates can result in a spray that obscures the operative site and floods the mouth.

Cutting rates at the normative flow rate of 15 ml/min observed here are comparable with those found in previous studies (Siegel and von Fraunhofer, 1996). However, CRs found with higher coolant flow rates clearly demonstrated an improved cutting efficiency, an increase in flow rate from 15 to 30 ml/min results in a 160% increase in CR. Further increase in flow rate above 30 ml/min does not improve CR. It is uncertain whether the problems associated with the increased coolant flow, such as flooding and possible obscuring of the operative site, justify the improved CR unless high speed, high efficiency extraction systems are available. Although higher coolant flow rates improve CR, further work will determine if there is an associated improvement in thermal protection to the pulp.

It is not clear why cutting efficiency is enhanced by higher coolant flow rates. Notwithstanding the importance of water cooling in conserving pulpal health, few studies have addressed the role of coolants/irrigants in dental cutting efficiency. Surface (chemomechanical) interactions can occur between the coolant and cutting substrate and will increase the CR for both diamond stones and carbide burs with a variety of substrates (von Fraunhofer & others, 1989). The exact mechanism of chemomechanical effects (von Fraunhofer & others, 1989, Westwood and Ahearn, 1984) is unknown, but the

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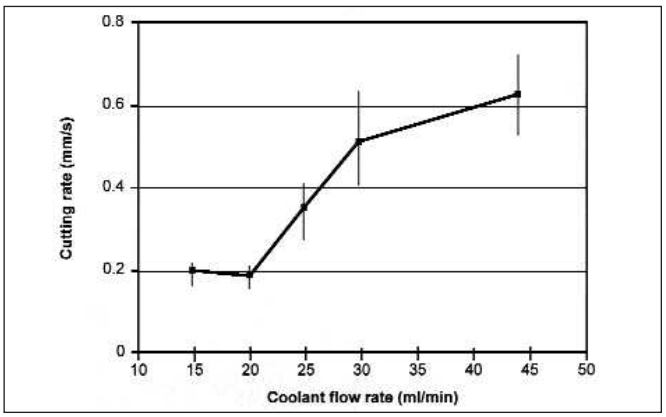

Figure 1. *Macor cutting rates (vertical lines denote standard deviations).*

effect has been confirmed with oral surgery burs during tooth dissection under water, saline and Ringer's lactate irrigation (Siegel & von Fraunhofer, 1999b). Preliminary studies indicate that while chemomechanical effects enhance CR, there is no associated temperature rise during the cutting process (von Fraunhofer, 1990). This result is to be expected since the reactions at the interface are electrochemical and involve charge transfer and, as such, do not involve heat (von Fraunhofer & others, 1989, Westwood, 1976; Westwood & Ahearn, 1984). Nevertheless, these chemomechanical-cutting studies were performed at relatively low coolant flow rates (15 ml/min) and the effect of flow rate on the CR was not addressed. A combination of chemomechanical effects and greater coolant flow rates may have a synergistic effect on dental cutting.

Examination of the burs after cutting under the five coolant flow rates indicates no difference in debris accumulation on the burs and previous work has shown that debris build-up achieves a limiting level within two minutes of the start of cutting with little change thereafter (Siegel and von Fraunhofer, 1996, 1997). This suggests that the higher flow rates do not affect the bur, rather, the effect is upon the substrate and possibly the dispersal of particulate matter released during cutting.

Dental cutting involves the use of very high bur rotation rates, and it is possible that a high fluid flow rate at the interface could cause bouncing or "aquaplaning" of the bur, but this does not appear to be the case. Material removal with a diamond stone is primarily dependent upon brittle fracture processes (Norling and Stanford, 1976; Xu & others, 1997), that is, coalescence of cracks formed in the substrate immediately behind the diamond chip. Consequently, the cutting rate is enhanced by factors that promote surface stress build-up and crack propagation. Such effects normally arise with additives in the coolant system (von Fraunhofer & others, 1989; Siegel & von Fraunhofer, 1999b), but in this study, the same coolant was used throughout, namely tap water. This suggests that the enhanced CRs reported may be due to subtle and localized charge effects induced at the bur-substrate surface by the higher fluid flow rates. While further study is underway, the use of higher coolant flow rates enhances cutting efficiency.

CONCLUSIONS

The use of higher coolant flow rates (25 ml/min) increases the rate of material removal. The mechanism underlying the improved CR, compared to that with lower flow rates, is uncertain but may be associated with induced charge effects at the bur-substrate interface. The data suggests that the use of higher coolant flow rates during tooth preparation procedures should increase cutting efficiency for dentists in practice.

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Effects of Cavity Form and Setting Expansion of Refractory Dies on Adaptability of Class II (MO and MOD) Fired Ceramic Inlays

M Hayashi • M Miura • N Nishimura
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Clinical Relevance

The setting expansion of refractory die material has significant effects on the adaptability of Class II (MO and MOD) fired ceramic inlays.

SUMMARY

This study investigated the effects of cavity divergence and setting expansion of refractory die material on the adaptability of Class II (MO and MOD) fired ceramic inlays.

Standardized Class II (MO and MOD) cavities with two kinds of lateral wall divergence (10 and 20 degrees) were prepared in epoxy resin blocks. A refractory die was prepared from an impression of the epoxy resin cavity in which the setting expansion ranged from 0.04 to 1.14%. A ceramic inlay was fired on each die. The fabricated inlay was inserted into the epoxy resin cavity, and the interfacial distance between the ceramic inlay and the cavity wall at the margin was measured using a reflecting microscope at x100 magnification. The internal fit was measured after sectioning the specimen longitudinally.

The results indicate that the setting expansion of the refractory die materials and the divergence of the lateral walls had significant effects on the adaptability of Class II (MO and MOD) fired ceramic inlays.

The inlays fabricated on the refractory dies with small setting expansion showed small internal gaps in Class II (MO) cavities. Significantly good adaptation was achieved when the setting expansion was 0.32% or less ($p<0.05$). The inlays fabricated on the refractory dies with large setting expansion showed small internal gaps in Class II (MOD) cavities. Significantly good adaptation was achieved when the setting expansion was 0.87% and greater ($p<0.05$).

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INTRODUCTION

A fired ceramic inlay is commonly used for ceramic restoration because the sintering technique has been clinically established, and general practitioners and

technicians can easily obtain the materials and equipment for fabrication. Based on the long-term investigation of fired ceramic inlays, 88% (van Dijken, Höglund-Aberg & Olofsson, 1998) or 92% (Hayashi & others, 1998) were found to be successful for six years, and the quality of the restoration is clinically acceptable as aesthetic and conservative restoration for molars.

However, marginal disintegration such as marginal fractures and wear of resin cement, was observed as weak points (van Dijken & others, 1998, Hayashi & others, 1998). Based on scanning electron microscopic findings six years after restoration, marginal micro-fractures were detected in 49% of the restorations, and wear of resin cement was observed in 36% (Hayashi & others, 1998). The marginal disintegration expanded and the micro-fractures could become more severe, resulting in restoration failure.

Moreover, an *in vitro* wear study revealed that greater loss of resin cement was found in wide gaps (150 µm) than in small gaps (50 µm), and concluded that good marginal fit significantly reduces the wear of resin cement in clinical conditions (O'Neal & others, 1991). Other studies recommended that the interfacial gap width remain less than 100 µm for ceramic inlays. Wide marginal gaps (over 100 µm) are considered a cause of marginal disintegration because the risk of food particles on the cement surface increases and causes wear (O'Neal, Miracle & Leinfelder, 1993, Leinfelder, Isenberg & Essing, 1989).

The reported average marginal gaps of Class II (MO) ceramic inlays were 80 µm for fired ceramic and Celay inlays, and from 170 to 200 µm for Cerec inlays (Siervo & others, 1994). In another study the marginal gap width of Class II (MO) Celay inlays was 60 µm (Kawai & others, 1995). The gaps of Class II (MOD) ranged from 40 to 80 µm for fired ceramic and Dicor inlays, and from 90 to 150 µm for Cerec inlays (Krejci, Lutz & Reimer, 1993). Other studies reported that the average marginal gaps of MOD ceramic inlays ranged from 46 to 57.6 µm for fired ceramic inlays (Dietschi, Maeder & Holz, 1992), and were 52 µm at the occlusal area and 200 µm at the proximal area for Cerec inlays (Fuzzi & others, 1991). These results indicate that the marginal gap width of ceramic inlays tend to vary widely.

Because many technicians found it extremely difficult to achieve perfect adaptation without adjustment after firing ceramic inlays, the fabricating procedure of fired ceramic inlays is regarded as difficult to master. Therefore, an easy technique must be established. In addition, it is important to achieve good adaptability of fired ceramic inlays to increase the life of the restoration.

Several factors, such as cavity form and expansion of refractory die materials, may have a marked effect on the adaptability of ceramic inlays. Therefore, the authors previously investigated the effect of cavity form and expansion of refractory die materials on the adaptability of Class I ceramic inlay (Hayashi & others, 2000). In addition, the authors examined the proper conditions of cavity form and expansion of refractory die materials to improve adaptability. The results indicated that cavities with smooth surfaces and larger divergence of lateral walls demonstrated good adaptation. The setting expansion of the refractory die materials also had a significant effect on adaptability. For Class I cavities, the setting expansion should be set at 0.2% or less to achieve good adaptation.

In clinical situations, Class II (MO and MOD) cavities are commonly used for ceramic inlay restorations. These cavities may have a specific superior expansion of die materials that can achieve better adaptability that is different from that of Class I; therefore, investigating the adaptability of Class II (MO and MOD) cavities is necessary.

The effects of cavity form and the setting expansion of refractory die materials on the adaptability of Class II (MO and MOD) fired ceramic inlays were investigated in this study to achieve better adaptation without additional adjustment after firing.

METHODS AND MATERIALS

A standardized, box-shaped Class II (MO and MOD) inlay cavity was prepared in an epoxy resin block (Epostick Resin, Nissin Co, Kyoto, Japan). The MO cavity had a length of 6 mm, a width from 3 to 7 mm and a depth of 2 mm at the occlusal portion, and a width of 7 mm and a depth of 4 mm at the proximal portion (Figure 1). The MOD cavity had a length of 7 mm, a width of 3 mm at the isthmus and 7 mm at the proximal portion, and a depth of 2 mm at the isthmus and 4 mm at the proximal portion (Figure 2).

Standardized preparation was conducted with a flat-ended tapered diamond bur mounted on a high-speed handpiece with a rotation speed of 250,000 rpm using a specially designed cavity preparation device (Ito Engineering Ltd, Kyoto, Japan). The special-ordered flat-ended tapered diamond burs (GC Co, Tokyo, Japan) had two different tapers (10° and 20°), and fine grits of diamond particles (25 µm). A new bur was used for each preparation. Using these diamond burs, the divergence of the proximal walls and the surface roughness of the cavity walls were precisely regulated. The preparations were assessed by stereomicroscopy (SMZ-10A, Nikon, Tokyo, Japan) at x20 magnification to confirm the desired shape of the cavity and the fracture-free margin. Then, five cavities were duplicated for each from each masterpiece with epoxy resin.

The G-Cera Cosmotech II system (GC Co) was used to evaluate the adaptability of fired ceramic inlays (Table 1). A plaster model was cast from the impression of the epoxy resin cavity using precise polyvinylsiloxane

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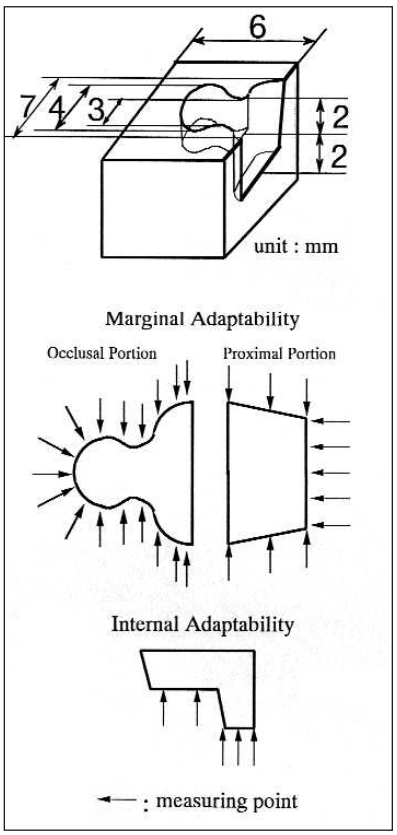

Figure 1. *Standardized Class II (MO) cavity. (top): Class II (MO) cavity form. Units shown are millimeters. (middle): Measuring points for marginal adaptability. (bottom): Measuring points for internal adaptability.*

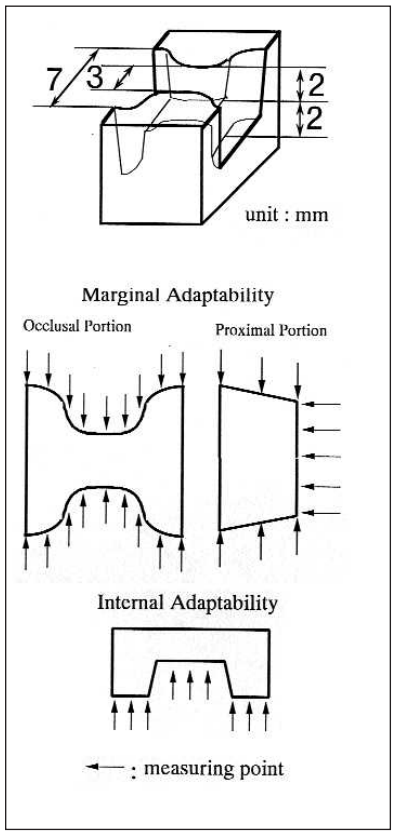

Figure 2. *Standardized Class II (MOD) cavity. (top): Class II (MOD) cavity form. Units shown are millimeters. (middle): Measuring points for marginal adaptability. (bottom): Measuring points for internal adaptability.*

impression material (Exaflex, GC Co). A refractory die was prepared from the duplicated impression with another type of precise polyvinylsiloxane impression material (Protesil, Krupp Medizintechnik, Essen, Germany) that had longer manipulation time.

The setting expansion rate of refractory die materials was controlled from 0.04% to 1.14% by varying the concentration of the colloidal silica solution at 0, 25, 33.3, 50, 75 and 100% as shown in Table 2. The measuring procedure of the setting expansion rate for the refractory die materials was described previously (Hayashi & others, 2000).

Ceramic inlays were prepared according to the manufacturer's instructions. Porcelain was built up on the refractory model and fired in a porcelain furnace (Ceramist A-IV, GC Co) at 970°C. After overhanging marginal edges were removed with diamond burs, observing by stereomicroscopy at x4 magnification to confirm the precise margin, the refractory model was removed using a sandblaster (Hi-Blaster, Shofu Ltd, Kyoto, Japan) with glass beads at 4 atm of pressure. The inlay was also replaced in the epoxy resin cavity to evaluate its fit.

The marginal adaptability was determined by measuring the minimal distance between the inlay and the cavity margin at 28 and 30 preselected points for MO and MOD cavities, respectively (Figures 1 and 2). A reflection microscope (Optiphot, Nikon) was used for the measurement at x100 magnification.

The inlay was then fixed in the epoxy resin cavity with cyanoacrylate bonding agent (Labo Sianone, Koatu Gas Kogyo Co, Tokyo, Japan). After fixing, the specimen was sectioned longitudinally into two pieces with a slow-speed diamond saw (Isomet, Buelher, Lake Bluff, IL). The internal adaptability was measured at five and nine points for MO and MOD cavities, respectively (Figures 1 and 2). Then, the marginal and internal adaptability was calculated as the average of all the measured data.

Two-factor factorial ANOVA was employed to analyze the effects of the setting expansion of die material and the cavity divergence on the adaptability of the ceramic inlays at a 95% confidence level, and the interaction of these two factors was also confirmed. Then, Scheffe's F test identified the significant differences in adaptability among the groups with different cavity divergence and the setting expansion at a 95% confidence level.

RESULTS

The Adaptability of MO Inlays

Table 2 shows the influence of the setting expansion of the refractory die material on the marginal adaptability of the Class II (MO) ceramic inlays. The marginal gap width could only be measured when the setting expansion was 0.32% or less in cavities of 10° and 0.41 or less in cavities of 20°. In other cavities, the gap width could not be detected precisely because large vertical gaps caused focusing of the microscope to be difficult. The marginal gap widths for cavities of 10° and 20° ranged from 28.3 to 36.7 μm, and the cavity divergence and the setting expansion showed no significant effects on the marginal adaptability (two-factor factorial ANOVA, $p>0.05$).

Table 1: *Materials Tested in This Study*

Ceramic System	Porcelain	Refractory Die Materials	Manufacturer
G-Cera Cosmotech II	G-Cera Cosmotech II Porcelain Batch #110321	G-Cera Cosmotech II Vest Powder Batch #281161 Liquid Batch #170372	G-C Co, Tokyo, Japan

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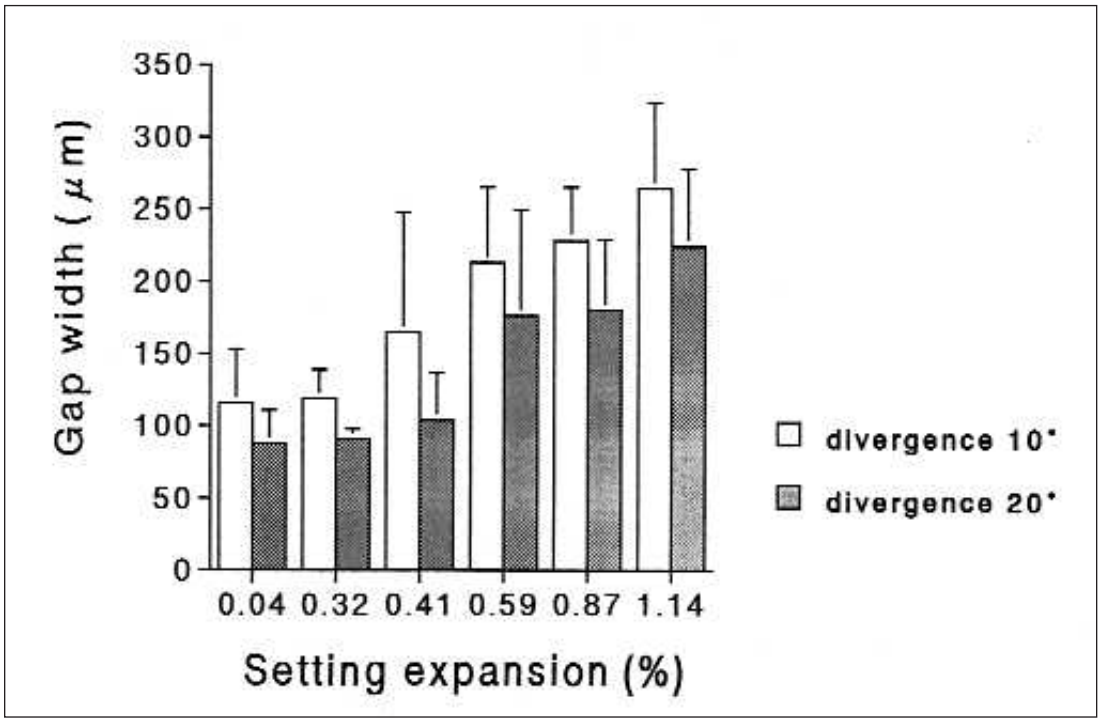

Figure 3. *The influence of the setting expansion of the refractory die material on the internal adaptability of ceramic inlays fabricated with Class II (MO) cavities of 10 and 20 degrees. Vertical lines denote SD.*

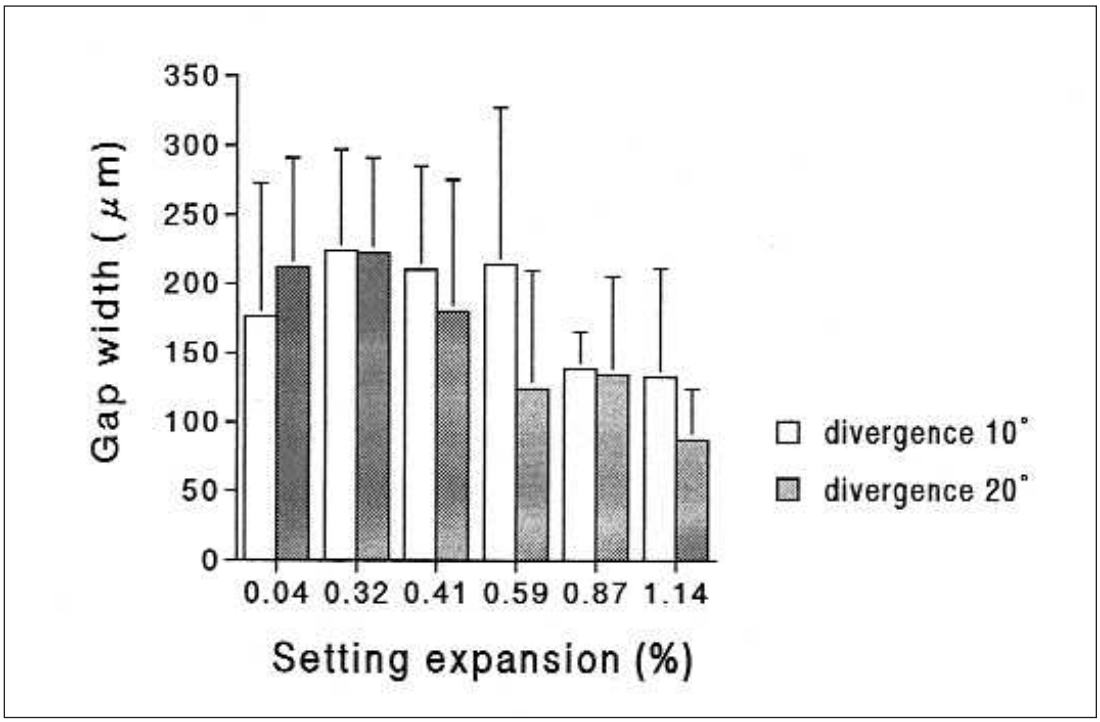

Figure 4. *The influence of the setting expansion of the refractory die material on the internal adaptability of ceramic inlays fabricated with Class II (MOD) cavities of 10 and 20 degrees. Vertical lines denote SD.*

Figure 3 shows the influence of the cavity divergence and the setting expansion of the die material on the internal adaptability of Class II (MO) ceramic inlays. The two factors (the setting expansion of the die material and the cavity divergence of the lateral walls) had significant effects on the adaptability (two-factor factorial ANOVA, $p<0.0001$). There was no interaction between these two ($p=0.6280$); therefore, the adaptability should be analyzed independently from the effects of these two factors. The cavities of 20° showed significantly smaller gaps than those of 10° (Shelf's F test $p<0.0001$).

For both types of cavities, significantly smaller gaps were observed when the setting expansion was 0.32% or less (Sheffe's F test, $p<0.05$). Smaller gaps were observed in the cavities with smaller setting expansion of the die material, and gaps of less than 100 μm were achieved only when the setting expansion was 0.41% or less in cavities of 20°.

The Adaptability of MOD Inlays

Table 3 shows the influence of the setting expansion of the refractory die material on the marginal adaptability of the Class II (MOD) inlays.

The marginal gap width could only be measured when the setting expansion was 0.87% and greater, and 0.59% and greater in cavities of 10° and 20°, respectively. The marginal gap widths for cavities of 10° and 20° ranged from 35.1 to 47.1 μm, and the cavity divergence and the setting

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Table 2: *The Influence of the Setting Expansion of the Refractory Die Material on the Marginal Adaptability of the Class II (MO) Ceramic Inlays*

Setting Expansion %	0.04	0.32	0.41	0.59	0.87	1.14
10° Cavities	33.7 ± 8.8	36.2 ± 7.4	-	-	-	-
20° Cavities	28.3 ±11.2	34.7 +± 5.4	36.7 ± 7.8	-	-	-

Means ± SD, Unit: µm, n=5, -:Measurement was impossible due to the large vertical dimension. There were no significant differences among the groups (p>0.05).

Table 3: *The Influence of the Setting Expansion of the Refractory Die Material on the Marginal Adaptability of the Class II (MOD)Ceramic Inlays*

Setting Expansion %	0.04	0.32	0.41	0.59	0.87	1.14
10° Cavities	-	-	-	-	40.1 ± 6.2	44.6 ± 7.7
20° Cavities	-	-	-	47.1 ± 7.2	38.6 ± 9.5	35.1 ± 5.9

Means ± SD, Unit: µm, n=5, -:Measurement was impossible due to the large vertical dimension. There were no significant differences among the groups (p>0.05).

expansion showed no significant effects on the marginal adaptability (two-factor factorial ANOVA, p>0.05).

Figure 4 shows the influence of the cavity divergence and the setting expansion of the die material on the internal adaptability of Class II (MOD) ceramic inlays. The setting expansion had a markedly significant influence on the adaptability (two-factor factorial ANOVA, p<0.0001), and the divergence also showed significant effects (p=0.0152). There was interaction between two factors (p=0.0046); therefore, the analysis was performed inclusively.

Smaller gaps were observed in the cavities with larger setting expansion of the die materials, and significantly smaller gaps were observed when the setting expansion was 0.87% and greater (Sheffe's F test, p<0.05). The internal gaps were below 100µm only in cavities of 20° and a 1.14% setting expansion.

DISCUSSION

Marginal adaptability is the most critical clinical criterion for the quality of the restoration because ceramic inlay restorations with precise margins demonstrated less marginal disintegration, which causes restoration failure (O'Neal & others, 1991). Marginal gap width should be measured to assess the adaptability of the restorations. On the other hand, the internal adaptability could demonstrate actual adaptability of the restoration, although only a few studies have investigated internal adaptability of ceramic inlays (Kawai & others, 1995, and Siervo & others, 1994). Moreover, a uniform and thin cement layer is the ideal condition for restorations. Therefore, in this study, both marginal and internal fits were evaluated to assess the adaptability of fired ceramic inlays.

Although many studies have investigated the adaptability of cemented ceramic inlays, this one examined the adaptability of uncemented fired ceramic inlays. The adaptability of the inlays was precisely measured without any effects of luting cement as its own thickness, its flow or operation error. The influence of the cavity form and setting expansion on the adaptability were clearly evaluated when fired ceramic inlays without cementation were investigated.

We selected some points to measure marginal and internal adaptability. The measurement points of the marginal adaptability can be considered sufficient and proper to assess the adaptability because the standard deviations of the marginal gaps were small.

Points at the bottom of the cavities only were selected to measure the internal fit (Figures 1 and 2) because these points precisely represent the internal adaptability. On the contrary, points at the proximal portion did not represent adaptability because the gap width at the proximal points became very thin both when the internal fit was perfect and when there was insufficient space to insert the inlay into the cavity. Therefore, the measuring points were selected from the bottom portion only, and the proximal points were eliminated.

Based on the investigation on Class I cavities, surface roughness and divergence of the cavities were found to significantly affect the adaptability of fired ceramic inlays (Hayashi & others, 2000). The smallest internal gaps were observed with smooth-surface cavities prepared using points with fine grits of diamond particles. Therefore, smooth-surface cavities were employed in this study. To achieve good adaptation, the cavity divergence of ceramic inlays should be larger than that of metal inlays. The Class I study showed that the cavities with larger divergence achieved more precise adaptability (Hayashi & others, 2000). However, marginal ceramics became thin and fragile if the divergence of the cavity walls was large. Based on these findings, the degree of divergence of the lateral walls was set at 10° and 20°. Ten degrees was slightly larger than that of metal inlays, and 20° was the maximum divergence in clinical conditions.

Our Class I investigation indicated that the setting expansion of refractory die materials should be under

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0.2% to achieve good adaptation (Hayashi & others, 2000). From the findings of this study, it should be set under 0.3% for MO cavities. Both Class I and MO cavities are typical internal ones; therefore, it is necessary to control the setting expansion under 0.2% so that the ceramic inlays are not larger than the original cavity size.

On the contrary, for MOD cavities, it should be set over 0.87%. MOD cavities have both internal and external elements in one cavity; the isthmus is an internal element and proximal portions are external. To achieve good adaptation, the isthmus should be longer than the original cavity and the proximal portion should be smaller. Our results showed that the external element affected the adaptability more strongly than the internal element because the larger expansion of dies made the adaptability more precise. Therefore, MOD cavities should be treated as external.

We concluded that to achieve adequate adaptability, the conditions of setting expansion of refractory die materials, depending on the cavity form, should be defined.

When the results of the adaptability of Class I and Class II (MO and MOD) cavities are compared, MOD cavities are the most difficult to achieve for good adaptability because MOD cavities have a more complicated form than Class I and MO cavities. To improve the adaptability of MOD cavities, the cavity divergence should be set at 20° and a large setting expansion of die materials should be employed.

The marginal adaptability of other ceramic inlay restorations has been reported, and the average marginal gap width varied from approximately 40 to 200 µm (Kawai & others, 1995, Siervo & others, 1994, Krejci, Lutz & Reimer, 1993, Dietschi, Maeder & Holz, 1992, Fuzzi and others, 1991). Based on these results, the marginal gap width observed in this study may be regarded as clinically acceptable and equivalent or superior to other reported ceramic inlays.

Few studies have investigated internal adaptability (Kawai & others, 1995). Most have focused on marginal adaptability only (Siervo & others, 1994, Krejci, Lutz & Reimer, 1993, Dietschi, Maeder & Holz, 1992, Fuzzi and others, 1991). The mean internal gaps of Celay inlays ranged from 36 to 53 µm for Class I and from 61 to 78 µm for Class II (MO) (Kawai & others, 1995). These results indicate that, in terms of adaptability, Celay inlays are superior to firing ceramic inlays.

The thickness of luting resin cement ranged from 3 to 59 µm (Inokoshi & others, 1993). These widths are required as marginal and internal gaps. On the other hand, the wear of resin cement, which may result in marginal fractures of ceramic inlays, proceeds rapidly when the marginal gap width is over 100 µm (O'Neal & others, 1993). Therefore, the optimal gap width may be greater than 50 µm and less than 100 µm. In this study, although MO inlays achieved suitable adaptability under various conditions, MOD inlays did not readily achieve proper adaptation. To improve the adaptability of MOD ceramic inlays, further investigations concerning the correlation between porcelain and refractory die materials are needed.

CONCLUSIONS

The setting expansion of refractory die materials had a significant effect on the adaptability of MO and MOD ceramic inlays. The setting expansion of the die material should be set at 0.32% or less for MO cavities and at 0.87% and greater for MOD cavities to achieve good adaptation.

Acknowledgments

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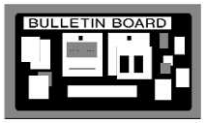

30th Annual Meeting of the Academy of Operative Dentistry

22-23 February 2001, Fairmont Hotel, Chicago, IL

The theme of the 30th annual meeting of the Academy of Operative Dentistry is **2001 – An Operative Odyssey for All Ages** and offers a wide variety of topics for the clinician. Thursday opens with Dr James Dunn's presentation, "Naturally Shaded Composite Resins – A New Family of Direct Restoratives," followed by Dr William Kohn with "Practice-Based Disease Control and Prevention Issues." Dr Jens Andreasen will give the Buonocore Memorial Lecture entitled, "Bonding Techniques in Dental Traumatology." Thursday afternoon features Dr Thomas Hilton (Cavity Sealers, Liners and Bases in Restorative Dentistry), Dr Howard Strassler (Periodontal Splinting with Direct Adhesive Fiber-Reinforced Composite) and Dr Conrad Cloetta (Suggestions for the Fabrication of Gold Restorations). Friday's essayists include Dr Robert Feigal (Creative, Contemporary Operative Dentistry for the Youngest Patient), Dr Kenneth Shay (Restorative Techniques and Biomaterials for the Older Adult) and Dr Van Haywood (Tooth Whitening: Answers and Applications). The essay session will be complimented by an outstanding Table Clinic program on Friday afternoon.

The theme for companion activities is **An Art Adventure**. Thursday's functions are a "Continental Breakfast at the Fairmont" and a program with Greta Wiley, one of the country's outstanding book-dramatists. Friday begins with a tour of both the Wood Street Gallery and the Portals Gallery followed by a delicious lunch at Emilio's Tapas Sol y Nieve restaurant highlighted by the special performance of a Flamenco dancer.

Finally, the Gala Reception on Thursday evening will be a marvelous opportunity for meeting with friends and colleagues to discuss the various presentations, the days activities and…what else…operative dentistry. For meeting information, please contact Dr Gregory Smith, PO Box 14996, Gainesville, FL 32604-2996; Fax (352) 371-4882. Hope to see you in Chicago!

Funding for Students' Research in Operative Dentistry

Students wanting to carry out research related to Operative Dentistry may apply for a Ralph Phillips Research Award, which is sponsored by the Founder's Fund of the Academy of Operative Dentistry.

The application should consist of a protocol (and 15 copies) outlining the background, aim/hypothesis to be tested, the methodology to be employed, a time schedule, and the expected outcome of the study. The protocol should not exceed three double-spaced type written pages, and a budget page (including where the funds should be sent provided the Award is granted). The budget may not exceed $2,600.

If an abstract based on the research and acknowledging the support from the Academy of Operative Dentistry is accepted for presentation at the IADR/AADR meeting in 2002, additional travel funds not exceeding $1,000, will be made available to the awardee.

A Faculty Advisor should be named and he/she should co-sign the application. The application must be submitted by December 15, 2000 to:

Academy of Operative Dentistry, Research Committee
c/o Dr Ivar A Mjor, Chairman
UFCD, Box 100415
Gainesville, FL 32610

Applications may also be submitted by e-mail to: imjor@dental.ufl.edu followed by one signed original by mail to the above address. The awardees will be announced during the Annual Meeting of the Academy of Operative Dentistry February 21-23, 2000.

Classifieds: Faculty Positions

University of Saskatchewan—College of Dentistry

The College of Dentistry is implementing an aggressive program of curriculum renewal, faculty renewal and research intensification. This position is a key part of that process. Candidates must have a strong commitment to teaching and research. A state of the art clinical facility has recently been installed, as well as a new SciCan Ultra Clinic, to complement our well-designed patient clinic. We are seeking an Assistant Professor, full-time tenure track, in the Department of Community & Clinical Dentistry. The position is available July 1, 2001. Salary is commensurate with experience and qualifications. Responsibilities include didactic and clinical instruction of undergraduate students in Operative Dentistry, innovative research and some administration. Graduate qualifications and practical experience at the Masters level is preferred. Effective computer skills are a prerequisite. Private practice is encouraged and available on site.

The University is committed to Employment Equity. Members of designated groups (women, Aboriginal people, people with disabilities and visible minorities) are encouraged to self-identify on their applications. This position has been cleared for advertising at the two-tier level. Applications are invited from qualified individuals regardless of their immigration status in Canada. Further information about our College and its programs are available at www.usak.ca/dentistry. Please submit application complete with curriculum vitae, credentials, a statement of teaching and research interests, and the names of three references to: Dr D Tyler, Department of Community & Clinical Dentistry, College of Dentistry, University of Saskatchewan, 105 Wiggens Road, Saskatoon, Saskatchewan, Canada, S7N SE4.

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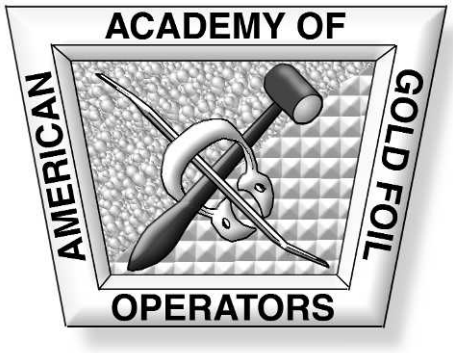

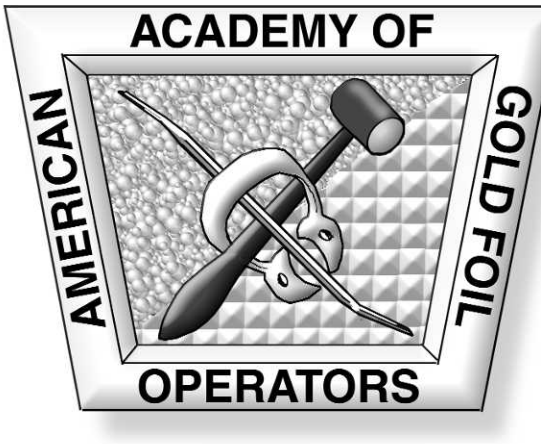

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