# 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 *is proud to present the first in a series of Recommendations for Clinical Practice published under the auspices of the Academy of Operative Dentistry with the support of the Operative Dentistry Section of the American Dental Education Association. These recommendations are based on the best available clinical and scientific information and represent countless hours of work by the Special Projects Committee of the Academy of Operative Dentistry. They are intended to serve as guidelines for the dental practitioner and, hopefully, will provide all clinicians with the information they need to deliver modern, evidence-based, quality health care to their patients. The following is provided as background on the genesis of this project, the development process and the goals for the future. The* Journal *welcomes comments and suggestions from our readership.*

*Michael A Cochran, Editor*



# The Academy of Operative Dentistry Recommendations for Clinical Practice

In 1996, the Executive Council of the Academy of Operative Dentistry proposed the formation of a consortium to develop guidelines for what should be currently taught at our dental schools by Operative Dentistry Departments/Divisions/Sections. During the course of that year, a Special Projects Committee was recruited to discuss the charge and form a plan for the development of these guidelines. The original committee consisted of Drs Thomas Berry, Richard McCoy, Craig Passon, James Summitt, Edward Swift, Jr and Peter Triolo, Jr.

The first meeting of the committee was held during the Annual Meeting of the Academy in February 1997. Lengthy discussions led to the consensus that the best approach would be to develop Academy supported "Recommendations for Clinical Practice." These recommendations would be based upon quality research, taking into consideration such factors as common practice, prudence, ethical judgment and the like. As work progressed, it became apparent that the Operative Dentistry Section of the American Dental Education Association shared an interest in the goals we hoped to achieve. Therefore, the proposal of creating "Recommendations for Clinical Practice" was presented to the Executive Councils of both groups. Each approved the proposal and supplied funding for the project. At this point, the committee membership was expanded to include a number of private practitioners and a representative from the Academy's European membership. New members included Drs Murray Bouschlicher, Richard Kloehn, William Morris and Nairn Wilson.

| Table 1: *Recommendations for Clinical Practice—Proposed Topics* |
|---|
| Fissure Caries |
| Smooth Surface Caries |
| Root Caries |
| Non-Carious Cervical Lesions |
| Tooth Fractures |
| Defective Restorations |
| Tooth Sensitivity |
| Occlusal Problems |
| Endodontically-Treated Teeth |
| Teeth Requiring Foundation Restorations |

Table 2: *Working Definitions of Terms*

**Examination**–Scrutiny or investigation for the purpose of making a diagnosis using clinical, radiographic and/or laboratory means.
*Source–Glossary of Operative Dentistry Terminology*.

**Diagnosis**–A determination of the nature of a disease. The art of distinguishing one disease from another.
*Source–Dorland's Medical Dictionary.*

**Prognosis**–An opinion of the prospects for success of a treatment.
*Source*–Adapted from *Glossary of Operative Dentistry Terminology.*

**Method**–A manner of performing an act or operation; a technique.
*Source*–Adapted from *Glossary of Operative Dentistry Terminology*.

**Risk Assessment**–Determination of the probability of suffering harm.
*Source–Dorland's Medical Dictionary*.

**Risk Management**–The method or process of influencing or controlling the probability of suffering harm.
*Source–Dorland's Medical Dictionary*.

**Patient Input**–Expression of patient's judgment, view, desire, appraisal formed in his/her mind about a particular dental treatment/procedure.
*Source*–AOD Special Project Committee.

**Expense**–Involves the cost related to the immediate value as well as the long-term benefit OR the monetary outlay to secure a benefit or bring about a desired result.
*Source*–AOD Special Project Committee.

**Surgical Treatment**–Procedure involving the cutting of tooth structure.
*Source*–AOD Special Project Committee.

**Non-Surgical Treatment**–Procedure that does not involve the cutting of tooth structure.
*Source*–AOD Special Project Committee.

**Procedure**–Series of steps by which a desired result is accomplished.
*Source–Dorland's Medical Dictionary*.

**Instrumentation**–Use of dental instruments in tooth preparation and placement of restorations.
*Source*–AOD Special Project Committee.

**Material Selection and Application**–Choice of appropriate materials and their placement to provide protection/medication of the dentin/pulp and restore the tooth to the desired function, health, relationships and appearance.
*Source*–AOD Special Project Committee.

**Preparation Design**–The specific form, features and extension of the cavity to eliminate the disease, provide maximum possible protection of the pulp and to enhance the placement of the restorative material and, ultimately, to assure the longevity of the restoration.
*Source*–AOD Special Project Committee.

**NOTE:**
These definitions were established to provide common focus and understanding. It should be recognized that they are working definitions and, as such, are subject to change if the need is recognized and agreed upon.

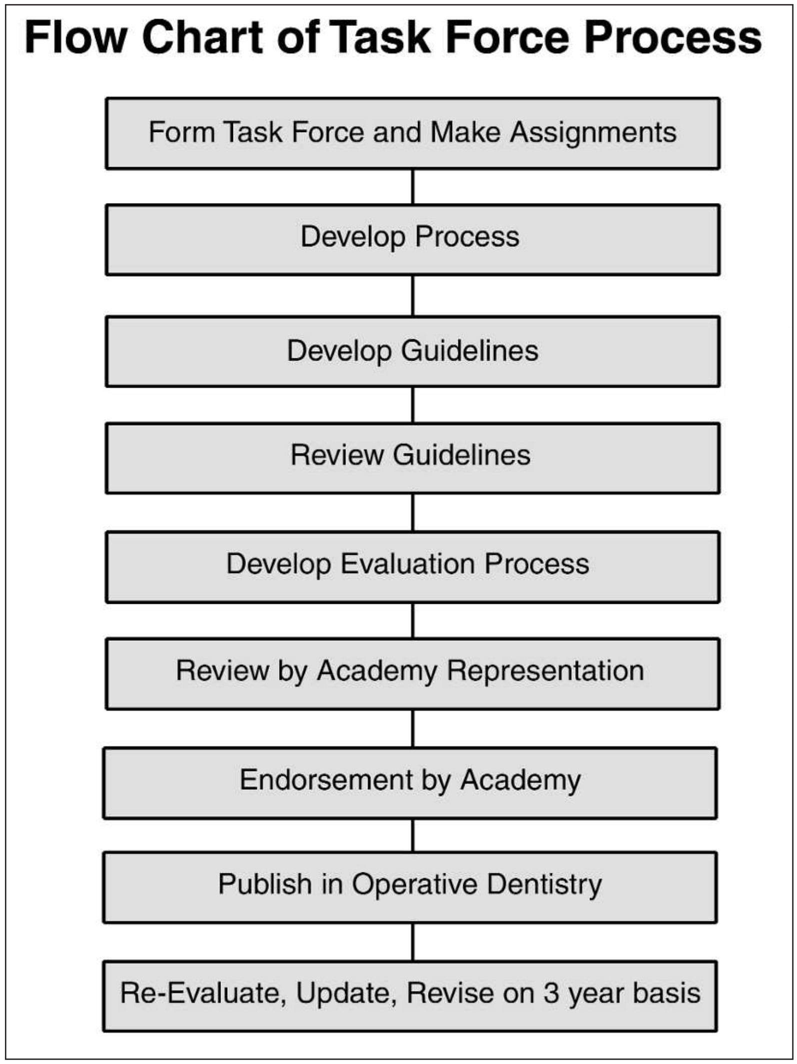


Figure 1. *The Special Projects Committee process for development, review, dissemination and re-evaluation of all recommendations.*

A subcommittee meeting was held in San Antonio, Texas in October, 1997. Flowcharts for the committee process (Figure 1) and for the specific recommendation process (Figure 2) were developed along with a list of topics for recommendations to be developed (Table 1) and working definitions for the committee (Table 2).

In February 1998, two subcommittees were formed and began drafting the recommendations for fissure caries and smooth surface caries. To assist in gathering information on what was currently being considered for practice and teaching, the Committee developed a survey that was distributed through the Operative Dentistry Section of the American Dental Education Association. The survey was sent to all dental schools to be used as the national agenda for the Conference of Operative Dentistry Educators regional meetings. Results of this survey were utilized in the development of the first recommendation and will continue to be

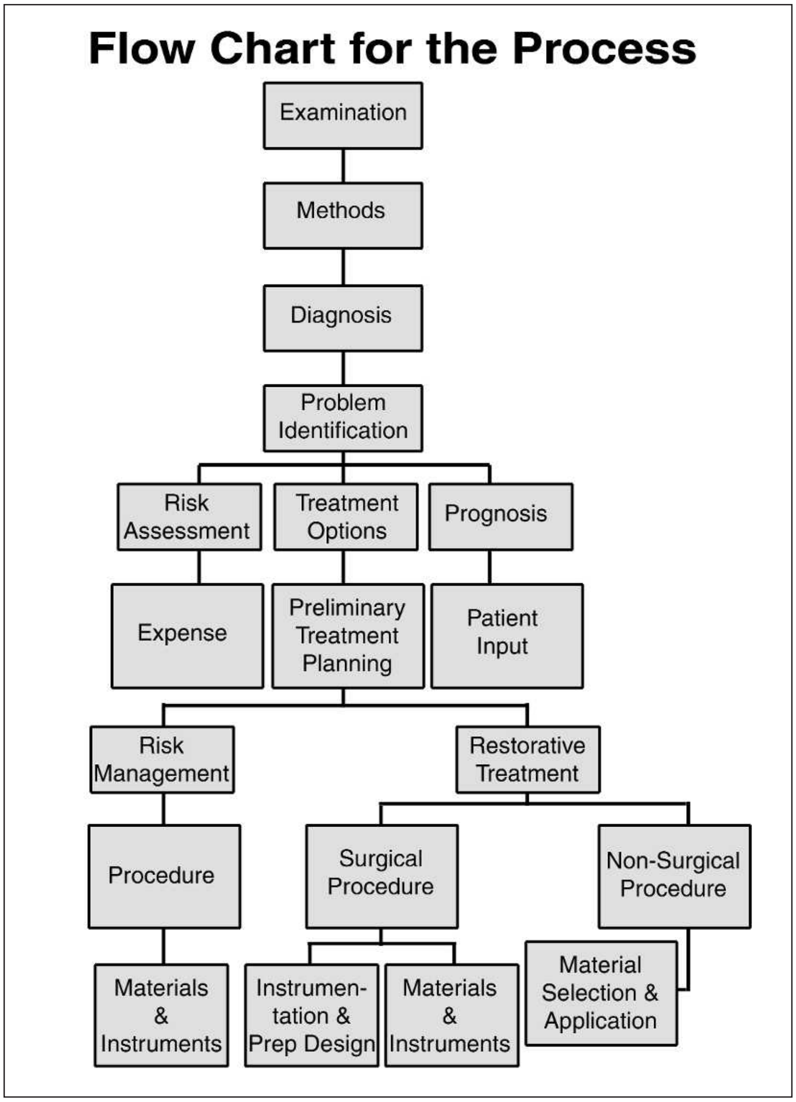


Figure 2. *The areas considered to formulate each specific "Recommendation for Clinical Practice."*

Table 3: *Five Levels of Evidence*

| Level | Strength of Evidence* |
|---|---|
| 1. | Strong evidence from at least one systematic review of multiple well designed randomized clinical trials. |
| 2. | Strong evidence from at least one properly designed controlled trial of appropriate size. |
| 3. | Evidence from well designed trials without randomization, single group pre-post, cohort, time series or matched-case controlled studies. |
| 4. | Evidence from well designed non-experimental studies from more than one center or research group. |
| 5. | Opinions of respected authorities, based on clinical evidence, descriptive studies or reports of expert committees. |

*From: JA Muir Gray (1997) Evidence-based health care–how to make health policy and management decisions New York Churchill Livingstone p 61.

used for subsequent recommendations. The fissure caries subcommittee met in October of 1998 and wrote the first draft of the fissure caries document. The draft was distributed to all members of the committee for review of format and content.

During the 1999 annual meeting of the Academy of Operative Dentistry, the committee reviewed the document and determined that a number of changes needed to be made and that references were required for a number of the statements. The committee reworked the document during the summer of 1999 and submitted it for final approval. It was also decided to use the Academy journal, *Operative Dentistry*, to publish the recommendations as they were completed. In this way, feedback from reviewers and readers will be used to improve subsequent recommendations.

The primary intent throughout this process has been to follow the initiative of evidence-based health care. According to Gray (Table 3), there are five levels of evidence relevant to clinical decision making. In dentistry, rarely is evidence of the highest (first) order available, so clinicians have to use the next highest level. Knowing that one level of evidence is better than another is important when making decisions about the treatment of patients.

The process of evidence-based health care has three important steps according to Ismail, Bader & Kamerow (Systematic reviews and the practice of evidence-based dentistry: Professional and policy implications *Journal of the American College of Dentists* **66(1)** 5-12 1999). The first is asking a clinically relevant question that, if answered, can help clinicians to provide better care to their patients. The second is a systematic review of all the evidence that may help to answer a clinically relevant question. The third step is to transfer the evidence-based conclusions into practice, which is the purpose of this project.

Peter T Triolo, Jr, Chair
Special Projects Committee

*Operative Dentistry*, *2001*, **26,** 324-327

## Recommendations for Clinical Practice

# Fissure Caries

### INTRODUCTION

The Academy of Operative Dentistry has developed the following recommendations on diagnosis and treatment of fissure caries in general practices, whether private or institutional. Patients should be informed of the disease process, methods of prevention and reversal, treatment alternatives, expected outcomes, potential sequelae and the part they should play during and subsequent to treatment. Failure to appropriately prevent and treat fissure caries can result in loss of teeth or tooth structure, the weakening of teeth and the perpetuation or increased risk of developing additional caries lesions.

**Clinical Assessment and Diagnosis**

**A. Definitions**

*Dental caries* is a process that brings about the progressive demineralization of the inorganic component of the tooth, accompanied by disintegration of the organic portion. It is primarily a bacterial disease but has a muitifactorial etiology (*Glossary of Operative Dentistry Terms*, 1983). A caries lesion is initiated when demineralization of surface tooth structure occurs, caused by acids generated by organisms within attached dental plaque (Featherstone, 1996). Removal of the causes of caries and the use of remineralization strategies can bring about remineralization of early lesions (Koulourides & Chien, 1992; Lagerlof & Oliveby, 1996; Sela & others, 1994).

A *dental groove* is a linear channel between enamel elevations, such as cusps and/or ridges. A *fissure* is a developmental linear cleft, often at the base of a groove, usually found in the occlusal, and often the facial and lingual, surfaces of posterior teeth, and in the lingual surfaces of anterior teeth (*Glossary of Operative Dentistry Terms*, 1983).

*Fissure caries* is the caries process occurring in enamel and/or dentin surrounding the fissures of teeth.

**B. Clinical Features and Methods of Assessment**

It has been demonstrated that the use of a sharp explorer, as a means to detect fissure caries, is neither valid nor reliable (Lussi, 1993; Lussi, 1996; Penning, van Amerongen, Seef & ten Cate, 1992). Demineralization of dentin at the base of a fissure may be detected radiographically (Pitts, 1993; Ricketts & others, 1993; Ketley & Holt, 1993), but the lesion must be somewhat advanced to be detectable with radiographic means (Creanor, & others, 1990; Espilid, Tveit & Fjelltveit, 1994; Sawle & Andlaw, 1988). Digital radiography has been demonstrated to provide additional diagnostic reliability (Wenzel, Larsen & Fejerskov, 1991).

The primary means for detection of fissure caries lesions at present is visual inspection during clinical examination (Dodds, 1993). To enhance visual detection of fissure caries, good light, dry teeth and magnification are necessary (Ekstrand & others, 1995). Cavitation of enamel and dentin adjacent to a fissure is an indication for restorative treatment. Changes in color and opacity of the enamel adjacent to a fissure can be indicative of demineralization of dentin under the enamel (NIDR, 1989).

Several methods for potentially increasing reliable detection of dentinal caries lesions and caries activity at the base of fissures are being studied. These include electrical impedance (Bader & Brown, 1993; Longbottom & others, 1996; Rickets, Kidd & Beighton, 1995; Pitts & others, 1996; Verdonschot & others, 1992; Berdonschot & others, 1993) and quantitative laser fluorescence (Lussi & others, 1998; Longbottom & others, 1998; Reich & others, 1998). If these are developed to a high degree of reliability and validity, they may supplant or augment currently used methods of diagnosis.

### THERAPEUTIC GOALS

The goals of treatment are to reduce the etiologic microbiota and contributing risk factors in order to halt the caries process and stimulate remineralization. The goals of restorative therapy are to restore the tooth to a state of health, function and esthetic appearance and to prevent the recurrence of caries (Lutz, Krejci & Besek, 1997).

**Therapeutic Considerations**

The professional judgment of the practitioner is key to the treatment planning process, but professional judgment must be guided by scientific evidence. Integral to determining the most appropriate treatment for fissure caries is the caries risk status of the patient.

**A. Low Caries Risk** (JADA **Special Supplement, 1995)**

Therapeutic considerations for a tooth assessed as having demineralized dentin at the base of a fissure and/or demineralized enamel adjacent to a fissure in a patient with low caries risk include:

1. If the patient is truly in the low risk category (*JADA* Supplement, 1995), the caries is currently inactive. The area of demineralization in either enamel or dentin occurred previously when the patient's risk status was moderate or high. No restorative treatment is indicated. The patient factors that are sustaining the low risk status should be reinforced, and the patient should be recalled for examination annually.

2. If there is cavitation (loss of the integrity of the surface of the tooth due to caries) as a result of demineralization during a previous period of increased caries risk, the missing portion of the tooth may need to be replaced through restorative intervention. If so, the most minimally invasive procedure is recommended.

3. If there is indication that the patient's caries risk status will change (such as the development of a debilitating disease), protective procedures, such as fissure sealants, dietary modification, salivary stimulation and increased fluoride use, are recommended.

**B. Moderate or High Caries Risk** (JADA **Supplement, 1995)**

1. Questionable Caries—When dentin demineralization at the base of a fissure is suspected due to fissure morphology and enamel demineralization, moderate or high caries risk and/or other fissure caries in the patient's mouth, but cannot be confirmed by clinical examination or radiographically, a fissure sealant is the recommended treatment. The walls of the fissure should be cleaned to assure clean and sound (not demineralized) enamel for bonding. This can often be accomplished with a handpiece-driven brush and pumice. If the enamel walls of the fissures are heavily stained or demineralized, or if there is fixed debris in the fissures, they may be narrowly and shallowly opened with a small round bur (such as a #1/8 or #1/16 bur) or with air abrasion techniques. Then they should be etched, primed (Boksman & Carson, 1998; Choi & others, 1997; Donaldson & others, 1998; Waggoner & Siegal, 1996) and sealed with a resin fissure sealant (Kramer, Zelante & Simionato, 1993; Lygidakis, Oulis & Christodoulidis, 1994; Shapira & Eidelman, 1986).

2. Frank Caries—A frank fissure caries is detected radiographically and/or via visual means. It may or may not involve cavitation. When frank caries lesion is detected, removal of the demineralized tooth structure and placement of a restoration is indicated. The tooth preparation should not extend into non-carious areas of the tooth, including non-carious fissures. Instead, in those areas, fissures should be sealed as described above (Mertz-Fairhurst & others, 1998).

The selection of sealant and restorative procedures and materials depends on several factors. For small caries lesions, the carious dentin and overlying, unsupported enamel should be removed, and the missing tooth structure replaced using a direct restorative material. For the occlusal surface, direct restorative materials of choice are amalgam and composite resin.

For larger caries lesions, amalgam, composite resin and gold may be appropriate selections for direct restorations, but indirect techniques with cast gold, ceramic or resin should be considered. When a lesion is of sufficient size that its removal leaves a cusp or cusps weakened to such an extent that risk of fracture is great, the cusp(s) should be reduced and covered for protection (Reagan, Schwandt & Duncanson, 1989; Salis & others, 1987; Sorensen & Martinoff, 1984; Wendt, Harris & Hunt, 1987). An alternative could be a bonded restoration that also incorporates mechanical resistance form; recent evidence (Uyehara, Overton & Davis, 1998) indicates that reinforcement of weak cusps is achieved by amalgam bonding used with pins; however, further evidence is needed.

3. The factors that lead to low risk of caries should be taught to the patient and frequently reinforced, and the patient should be recalled at intervals appropriate for the level of caries risk (that is, as frequently as one month for high caries risk, varying to six months for patients in the moderate risk category).

## OUTCOMES ASSESSMENT

**A.** Satisfactory response to therapy should result in maintenance of, or conversion to, a low caries risk status for the patient, maintenance or restoration of pulpal health, and optimum longevity for any restorations. An appropriate initial interval for follow-up examination should be determined by the clinician based on caries risk status.

**B.** Factors that may contribute to the reduction of caries risk include effective compliance in maintenance of personal oral hygiene, effective use of topical fluorides, dietary compliance, adequate salivary function and absence of mental or physical disability.

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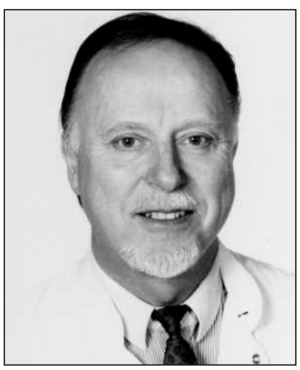
## Buonocore Memorial Lecture

# Adhesive Dentistry Applied to the Treatment of Traumatic Dental Injuries

Michael Buonocore

**JO Andreasen**



Jens O Andreasen

**SUMMARY**

**Dental adhesive techniques have led to a significant simplification of the immediate and definitive treatment of traumatic dental injuries. Composite restoration of fractured teeth, bonding of tooth fragments, the use of laminate veneers or porcelain onlays and resin retained bridges are some of the ways adhesive techniques are used to treat fractured teeth. Furthermore, splinting of luxated teeth almost entirely relies on the combination of adhesion and a flexible resin which simulates the mobility of a normal periodontal ligament during the healing period. The internal strengthening of immature root-filled teeth with composite using an adhesive technique may possibly prevent late root fractures caused by weakening of the tooth structure resulting from endodontic procedures. Finally, the adhesive principle using a retro-seal with composite after apicoectomy significantly increases the healing rate and healing mode.**

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Jens O Andreasen, DDS

## INTRODUCTION

Two major events have significantly changed the treatment and prognosis of traumatic dental injuries, namely, the use of evidence-based treatment procedures as they apply to (1) pulp and periodontal ligament healing after experimental dental injuries (Andreasen & Andreasen, 1994) and (2) the invention of adhesive dentistry (Buonocore, 1955) and its application to various phases of treating dental traumatology. Applying adhesive dentistry to traumatized teeth interested Michael G Buonocore early in his career. Thus, the Buonocore biography published by Ring (1992) mentions that Buonocore, in a conversation with Dr L Ripa, said, “Think about it: why don’t we have a procedure to treat a fractured anterior tooth by using a material with which we, like an artist with a brush, could build up that tooth to its natural form rather than using a pin or large crown?” (Figure 1).

The following discussion presents state-of-the-art adhesive dentistry as it relates to restoration of crown-

Figure 1. *M Buonocore (seated center) with Marianne Gilmore (left) and Director W McHugh (right) and postgraduate students (standing). Photo taken in front of the Eastman Dental Institute in 1973.*

fractured teeth, bonding of tooth fragments, resin-retained bridges, splinting of traumatized teeth, internal strengthening of endodontically-treated teeth and the use of adhesive techniques to achieve a bacteria tight seal of the root canal after apicoectomies.

## CROWN RESTORATIONS

Until the late '60s, temporary and permanent restoration of traumatized teeth in young individuals represented a severe challenge. Temporary treatment usually consisted of adaptation of preformed steel crowns, which implied significant esthetic problems even if the design was modified using various window preparations or tooth-colored staining of the steel crowns (Andreasen, 1972) (Figure 2A,B). The introduction of retention pins and composite to restore crown fractures presented an acceptable esthetic solution for a time. However, these restorations ran the risk of developing caries under the restoration due to a lack of stability of the restoration (Andreasen, 1972) (Figure 3A,B).

Since Buonocore (1955) discovered the adhesion of acrylic materials to enamel surfaces, this technique was later applied to the restoration of fractured anterior teeth (Ward, Buonocore & Woolridge, 1972; Buonocore & Davila, 1973). This procedure appeared to be a promising solution to an otherwise very difficult treatment problem, especially in children (Figure 4). During the '70s adhesive composite restorations almost became standard procedure in the treatment of crown fractures in children and adolescents, and often in adults (Jordan, 1974; Andreasen & Andreasen, 1994b). Initially, dentin coverage with a hard setting calcium hydroxide cement was recommended, but after the advent of dentin bonding, composite restoration has become more simplified, providing better retention of the restoration (Jordan, 1994).

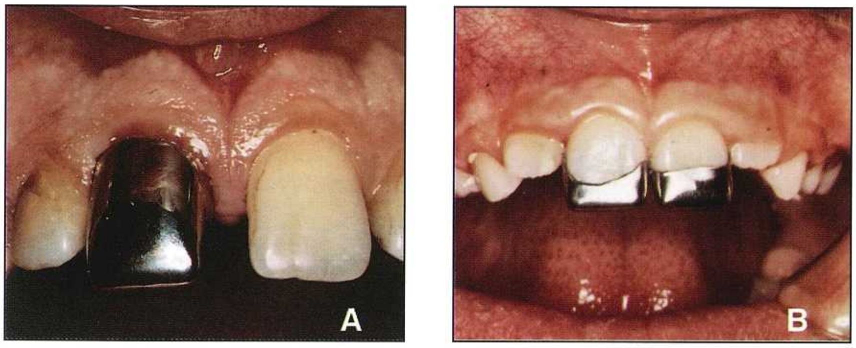


Figure 2A and 2B. *Steel crowns used for temporary coverage of exposed dentin before definitive treatment at adult age with a cast restoration or a jacket crown.*

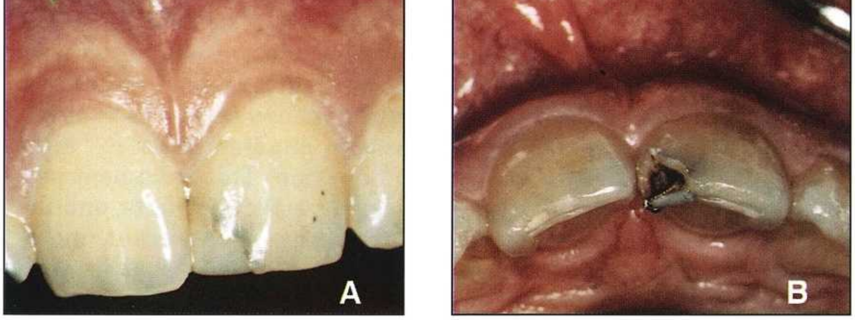


Figure 3A and 3B. *Deep caries developed under a leaking composite restoration retained by pins.*

Relatively few long-term studies exist on the longevity of these restorations, and only a few have comprised enough data to permit life table analysis (Roberts & Moffa, 1973; Jordan & others, 1977; Watkins & Andlaw, 1977; Smales, 1977; Ulvestad, 1978; Smales, 1983; Qvist, Ström & Thylstrup, 1985; Smales, 1991a,b). Smales' studies have demonstrated the half-life of anterior composite restorations, that is, replacement of 50% of restorations lasting eight to nine years overall, while Class IV restorations only had a half-life of four years (Figure 5). The results of current studies indicate that composite restoration of fractured crowns can only be considered a semi-permanent treatment. With improvements in the design of both composite materials and bonding techniques over the last decade, it could be expected that longevity could be improved. Recently, however, a disturbing report concerning the long-term survival of composite restorations used after trauma has appeared. All composites in that study (n=140) were replaced at least once, with an average of six renewals reported over a 15-year period of observation (Robertson, Robertson & Norén, 1997; Robertson, 1998).

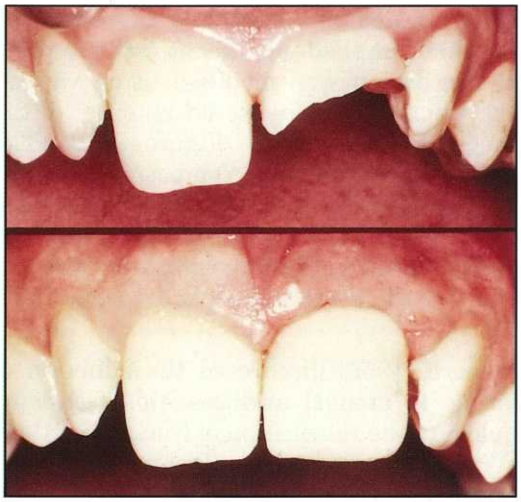

Figure 4. *Composite restoration of an anterior fracture using adhesive technique.*

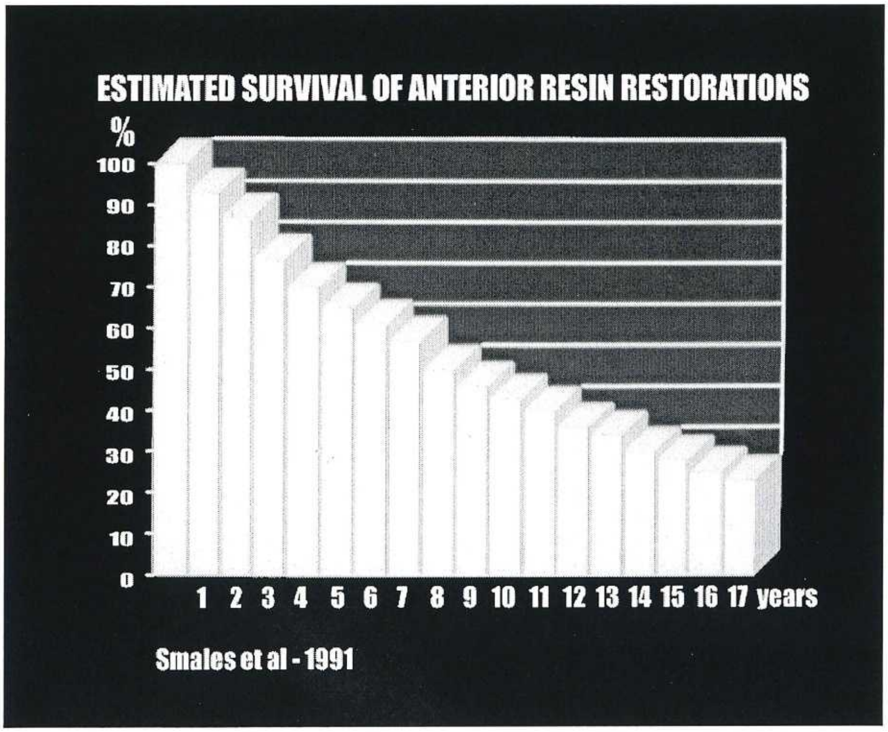


Figure 5. *Life-table analysis of longevity of anterior composite restorations (After Smales, 1991a,b).*

## BONDING TECHNIQUES FOR CROWN-FRACTURED TEETH

The first cases where crown fragments were reattached using a bonding technique (Mader, 1978; Tennery, 1978) were reported in 1978. Soon thereafter, a clinical study dealing with the long-term prognosis of fragment bonding appeared (Andreasen & others, 1986; Andreasen & others, 1995) (Figures 6A,B). Subsequently, a multi-center clinical study of long-term survival of fragment bonding in the treatment of fractured tooth crowns was carried out at three Scandinavian trauma centers (Andreasen & others, 1995). The study employed the technique described above, with enamel etching and Gluma dentin bonding agent for reattaching the coronal fragment. The observation period was up to 10 years. In addition, a group of fractured teeth was restored by fragment bonding using only acid etching and a polymerizing methacrylate resin. The calculated half-life of the restored teeth with the dentin bonding technique was about 2.5 years, and approximately 25% of the bonded fragments were still retained after 7.5 years. Half the teeth bonded with acid etching and without using a dentin bonding agent lost their retention within the first year in function (Figure 7).

An *in vitro* model using sheep teeth by which various aspects of the bonding procedure could be analyzed (Andreasen & others, 1991, 1993; Farik & others, 1998; Farik & Munksgaard, 1999) has been developed. These studies have shown that several factors may influence the strength of bonding, namely the type of dentin bonding system used (Andreasen & others, 1993; Farik & others, 2000a), drying of the fragment (Farik & others, 1998, 1999) and the initial use of a calcium-hydroxide coverage of dentin (Farik & others, 2000b). In the two latter instances, a significant decrease in the bonding strength was found.

Currently, no clinical studies reporting success rates using newer generations of dentin bonding systems have been published.

## LAMINATE VENEERS IN THE TREATMENT OF CROWN FRACTURES

Since 1983 when the first report on the long-term prognosis of laminate veneers was published (Calamia & others, 1987), a number of long-term studies have appeared (Andreasen & Andreasen, 1994). This procedure can be used in the treatment of extensive enamel cracks, loss of crown structure due to fractures, slight discoloration (gray or yellow) as well as of developmental disturbances in enamel, that is, after injuries to the primary dentition. This treatment procedure usually gives excellent esthetic results, and the long-term prognosis according to a recent meta-analysis study appears to be excellent, that is, with more than 90% predictability of survival at three years (Kreulen, Creugers & Meijering, 1998).

A variation of this procedure has been the use of porcelain onlays in the treatment of crown fractures (Toreskog & Rehnberg, 1995; Toreskog, 1999). By using this technique, a very shallow bevel extending only a few millimeters from the fracture surface and in contact with the gingival area was avoided (Figures 8A,B,C). A pleasing esthetic result may be obtained but, so far, no long-term results have been reported.

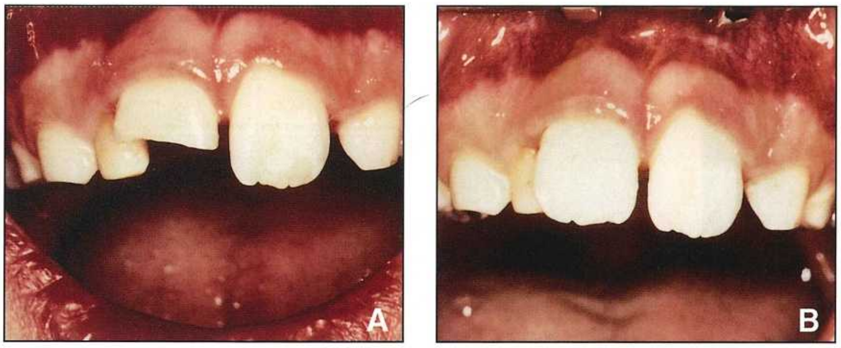


Figure 6A and 6B. *Bonding of a fractured anterior tooth immediately after bonding.*

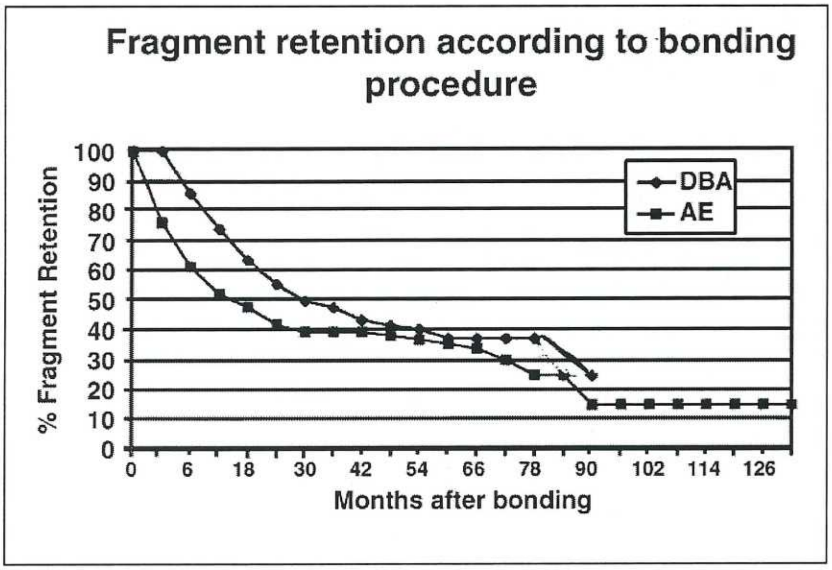


Figure 7. *Multi-center study on the retention of bonded fragments using either enamel bonding (AE) or enamel and dentin bonding (DBA) (after Andreasen & others, 1995).*

## RESIN RETAINED BRIDGES

A traumatic dental injury may imply immediate tooth loss, or healing complications may later result in extraction of the traumatized tooth. On a population basis, such injuries have been found to occur with an annual incidence rate of 0.02%-0.04% (Andreasen, 1996). Before the advent of adhesive dentistry, a typical treatment solution appeared to be a conventional fixed bridge. This procedure seems to have a reasonably good long-term prognosis (Winter, 1994; Creugers, Käyser & van't Hof, 1994; Scurria, Bader & Shugais, 1998) (Figure 9). The frequent occurrence of pulpal complications has been a concern due to extensive exposure of dentin during the preparation (Kerschbaum & Voss, 1979). Development of the acid etch technique has significantly changed this problem (Creugers, 1994). Limited preparation of the abutment teeth does not represent a hazard to the pulp, which is of great importance especially in trauma cases where the pulp has often already suffered from the sequelae of a luxation injury. Although the long-term prognosis still does not fully match conventional bridges, anterior Maryland type bridges appear to have a reasonably good long-term prognosis (Creugers, 1994) (Figure 10).

## ADHESIVE TECHNIQUE USED IN SPLINTING TRAUMATIZED TEETH

Traditionally, firm splinting of luxated teeth has been considered an absolute necessity to assure optimal periodontal ligament healing (Andreasen, 1972). However, in animal experiments in the early '70s, serious doubt was cast upon this treatment principle as no splinting of replanted monkey teeth

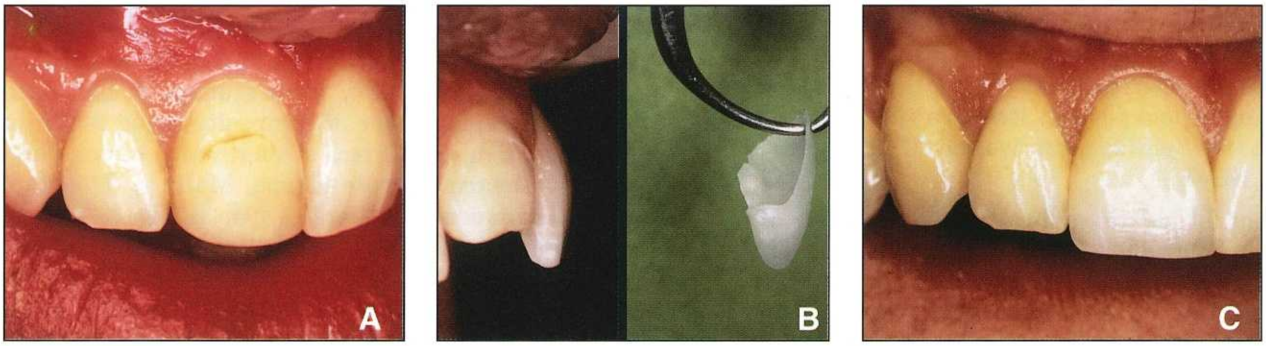


Figure 8A, 8B and 8C. *Restoring a fractured right central incisor with a porcelain onlay (courtesy of Dr S Toreskog, Gothenburg, Sweden).*

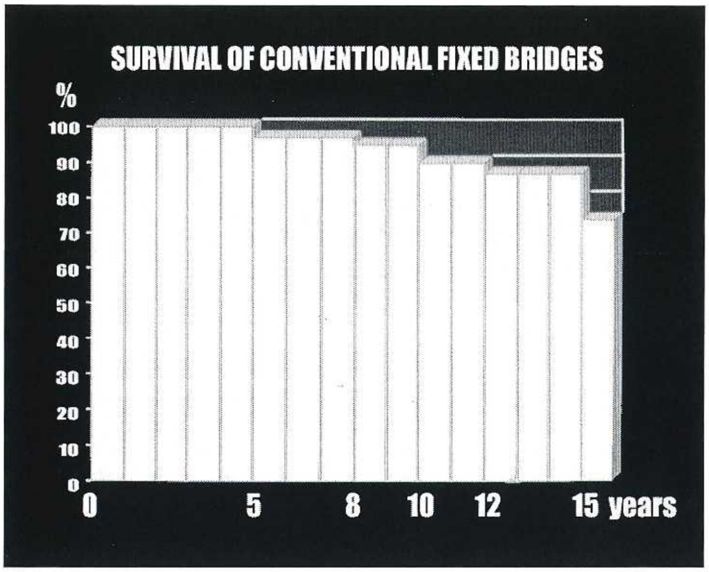


Figure 9. *Long-term survival of conventional fixed bridges (after Creugers, Käyser & van't Hof, 1994).*

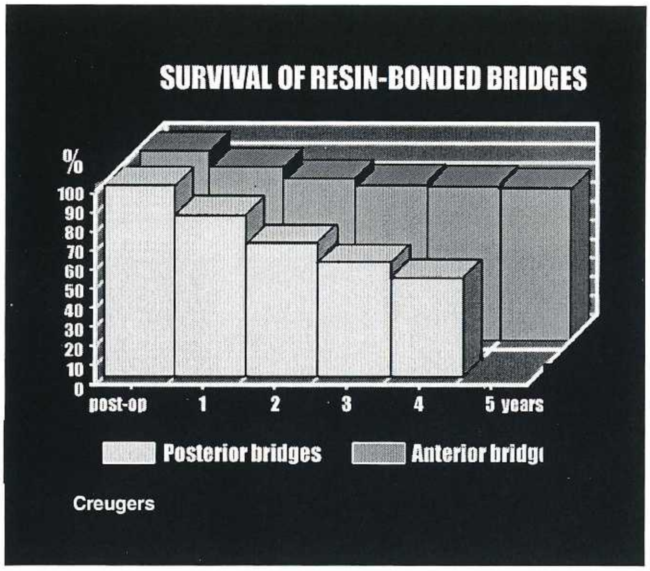


Figure 10. Long-term survival of acid etch bridges (after Creugers, 1994).

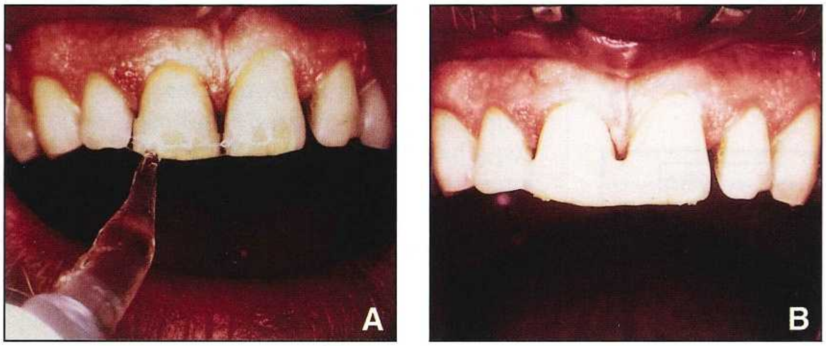


Figure 11A and 11B. *Modern splinting using a temporary crown and bridge material (Luxatemp) to splint a luxated tooth.*

appeared to favor optimal periodontal ligament healing as well as more complete pulp healing compared to rigid splinting (Andreasen, 1975; Kristerson & Andreasen, 1983; Andersson & others, 1985; Mandel & Vidik, 1989).

Teeth have been traditionally splinted with arch wires, arch bars and various types of cap splints (Andreasen, 1972). In each of these instances, the adaptation of these splints may apparently result in additional trauma to the periodontium and/or the pulp. Furthermore, the close proximity of these splints to the gingival margin could possibly lead to a risk of bacteria invasion in the periodontal wound (Andreasen & Andreasen, 1994).

The advent of dental adhesion has dramatically changed the whole philosophy of splinting. After etching the incisal part of the enamel, the application of a flexible resin material, as used for a temporary crown or bridge material, represents a simple and easily performed treatment procedure. It creates a mobility pattern of the luxated and splinted tooth which comes very close to the mobility of a non-injured tooth (Andreasen, 1975; Oikarinen, 1987, 1988; Oikarinen, Andreasen & Andreasen, 1992) (Figures 11A,B). Apparently, this restricted mobility induces a favorable condition for periodontal ligament healing (Mandel & Vidik, 1989). A recent long-term study of root-fractured teeth treated with five different splinting procedures found that the adhesion technique using a flexible splinting device (glass fibers + resin) showed the highest predictability of not only pulp healing, but also formation of a mineralized barrier at the fracture site (Cvek, Andreasen & Borum, 2001).

## STRENGTHENING ROOT CANAL-TREATED TEETH USING ADHESIVE TECHNIQUES

It is a well known phenomenon that root canal-treated teeth, where pulp necrosis has occurred before the root has completely formed, run a significant risk of either spontaneous root fracture or fracture after minor injuries (Cvek, 1992). This appears to result from a weakening process of the dentin due to the endodontic procedures. In several *in vitro* studies, it has been shown that replacement of composite using a dentin bonding system gives extra strength to the root when tested by shearing stress (Trope, Maltz & Tronstad, 1985; Hernandez & others, 1994; Rabie & others, 1985; Katebzadeh, Dalton & Trope, 1998; Pene, Nicholls & Harrington, 2001). It remains to be documented whether the strengthening procedure is sufficient in a clinical situation to avoid root fractures in endodontically-treated teeth with incompletely formed roots.

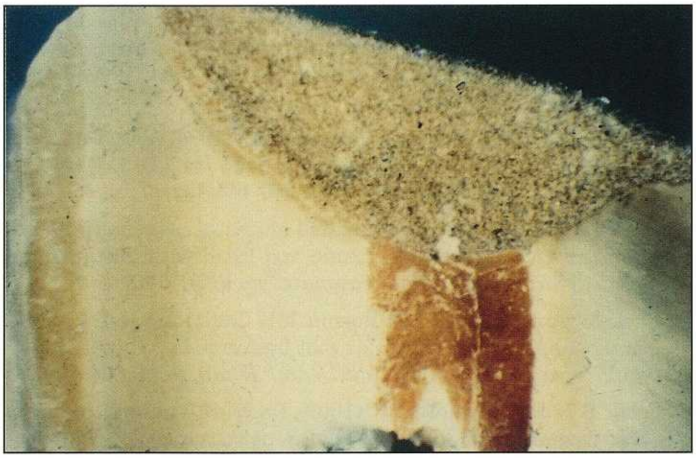

Figure 12. *Dentin bonded composite used to seal the root canal and the exposed dentin (from Rud & others, 1991a).*

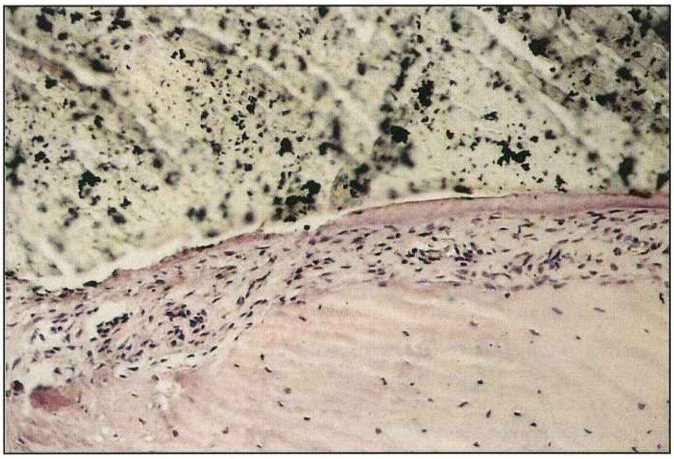

Figure 13. *Dentin bonded composite resin used to seal an infected root canal in a monkey canine, where the apex has been resected. Note the bonding of the material to the dentin and the deposition of cementum and periodontal ligament fibres on the composite (from Andreasen, & others, 1989).*

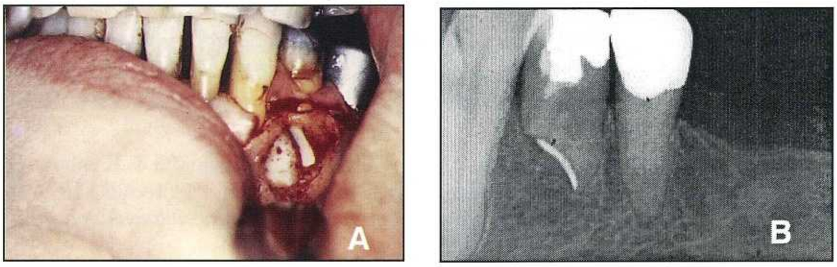


Figure 14A and 14B. *Healing after the use of dentin bonded composite resin in an apicoectomy case. Note complete reformation of the periodontal ligament (from Rud, Munksgaard & Andreasen, 1991).*

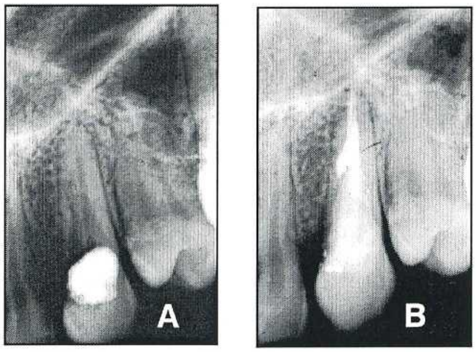


Figure 15A and 15B. *Cervical resorption treated by excavation of the resorption cavity and the use of dentin bonded material to fill the defect and strengthen the tooth (courtesy of Dr Rud, Copenhagen, Denmark).*

## DENTIN BONDED COMPOSITE USED AS A SEAL IN APICOECTOMIES

In 1989, a new treatment procedure was developed in apicoectomies using dentin bonded composite to seal an infected root canal after apicoectomy (Rud, Andreasen & Rud, 1989). In an experimental study in monkeys, it was found that composite used to seal a resected apex not only prevented bacteria from leaking out of an infected root canal, but also allowed new cementum and a periodontal ligament to be formed on the composite (Andreasen, Rud & Munksgaard, 1989; Andreasen & others, 1993) (Figures 12, 13 and 14). This procedure has created a series of new treatment possibilities in surgical endodontics, whereby teeth with complicated root canal anatomy or lateral root resorption can be sealed with a dentin bonded composite (Rud, Munksgaard & Andreasen, 1996) (Figures 14A,B and 15A,B). Long-term studies have found a significant increase in the healing rate of apicoectomies using dentin bonded composite as a retro-seal compared to the use of amalgam (Rud, Andreasen & Rud, 1989; Rud & others, 1991).

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## Clinical Research

# Pulpal Inflammatory Responses Following Non-Carious Class V Restorations

I About • PE Murray • J-C Franquin
M Remusat • AJ Smith



### Clinical Relevance

The interactions between cavity preparation and restoration events which result in pulpal inflammation have been characterized in 202 restored Class V cavities. This information explains how pulpal inflammatory activity can be minimized, and the probability of post-operative complications reduced.

### SUMMARY

**The effects of inflammatory activity following surgical intervention can injure pulp tissues; in severe cases it can lead to pulpal complications. With this article, the authors report on the effects of cavity preparation and restoration events and how they can interact together to reduce or increase the severity of pulpal inflammatory activity in 202 restored Class V cavities. Although some inflammatory activity was observed in the absence of bacteria, the severity of pulpal inflammatory activity was increased when cavity restorations became infected. Zinc oxide eugenol and resin-modified glass ionomer cement prevented bacterial microleakage in cavity restorations, with no severe inflammatory activity observed with these materials. Bacteria were observed in cavities restored with enamel bonding resin and adhesive bonded composites and were associated with severe grades of inflammatory activity. The cavity remaining dentin thickness influenced the grade of inflammatory activity. In the absence of infection, the grade of inflammatory activity decreased after 20 weeks post-operatively. In the presence of infection, the grade of pulpal inflammation remained stable until a minimum of 30 weeks had elapsed.**

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### INTRODUCTION

Whenever the tooth dentin-pulp complex is affected by caries, attrition, erosion, chemicals, abrasion and iatrogenic trauma, the pulpal response to these injuries can stimulate inflammatory activity (Brännstrom & Lind, 1965; Massler, 1967). Although the pulp injury caused by these effects can be important, in many cases the most severe tissue trauma is not a direct result of these environmental or accidental events, instead, it results from the surgical techniques and materials used to restore tooth structure following these events (Cox & others, 1992; Stanley, 1992; Kim & Trowbridge, 1998). This is because the immune system triggers an inflammatory response to limit tissue damage. Paradoxically, these inflammatory reactions can injure the pulpal cell populations and lead to pulp complications in response to cavity restorations, which may initially appear to be successful. Millar (1890) first highlighted the role of bacterial infection in causing pulp necrosis. Since then, a number of studies have implicated the presence of bacteria and their products as a pre-requisite for induction of the most severe forms of pulpal inflammatory activity (Bergenholtz & others, 1982). This explains why a decisive factor in the clinical success of restorative products is their ability to maintain an effective seal with the tooth cavity surfaces to protect the pulp from recurring subsequent injury resulting from bacterial microleakage in the restored cavity (Qvist, 1980; Kitasako & others, 1999). Although a clear causative relationship exists between pulp injury, infection and inflammatory activity, the question concerning the possible influence of the interactions between the variables of cavity preparation and restoration remains, as well as bacterial microleakage.

Severe forms of inflammatory activity can often progress to total pulpal necrosis and periapical lesion development with local bone destruction (Bergenholtz, 1990). Consequently, it is important to ensure that potential sources of injury that stimulate inflammatory activity are always minimized. Inflammatory activity may contribute to the high rates of primarily vital teeth exhibiting endodontic complications following cavity restoration (Zollner & Gaengler, 2000). However, information is limited, and pulpal inflammation following surgery remains largely uncharacterized. The advantage of the improved management of pulpal inflammation is that it may reduce the incidence of post-operative pulpal complications. Furthermore, once the pulp becomes inflamed, it becomes hypersensitive so that thermal, mechanical or osmotic stimuli encountered in normal function can cause intense pain. Consequently, a more complete understanding of the relationship between pulpal inflammation and cavity restoration events may also lead to further improvements in the clinical management of pain (Taylor & Byers, 1990).

This study characterized pulpal inflammatory activity in response to the presence or absence of bacteria, cavity-remaining dentin thickness (RDT) and placement of the following restoration materials: zinc oxide eugenol (ZOE), resin-modified glass ionomer cement (RMGI), enamel bonded resin (EBR) and adhesive bonded composite (ABC).

## METHODS AND MATERIALS

Two hundred and two non-carious intact first or second maxillary or mandibular premolars were scheduled for extraction for orthodontic reasons at the Marseille Hospital Dental Care Centres. Patients and their parents provided prior informed consent. Healthy patients ages 9–25 years had Class V cavities placed in the buccal surface of teeth, 1 mm above the level of the cemento-enamel junction. The standardized methods and procedures used in this study have been described elsewhere (Murray & others, 2000a,b). Briefly, rubber dams were fitted and preparation forms cut into the tooth dentin using the least possible pressure at a drill speed of 400,000 revolutions per minute with water spray coolant. Cavities were cut into the dentin to a range of cavity-remaining dentin thicknesses (RDT) between 0.008 and 2.933 mm, and occluso-gingival axial floor widths between 0.337 and 3.393 mm, with a mean of 1.943 mm. After post-operative intervals of 3 to 381 days, the restored teeth were extracted using local anesthesia, again with patient-parental informed consent.

All the restoration products were used strictly according to manufacturers' instructions, and the teeth were assigned to four experimental groups for restoration (Table 1). The first restoration group comprised a total of 11 ZOE cavity restorations (Kalzinol, De Trey Dentsply, Zurich, Switzerland) or a reinforced ZOE product (Intermediate restoration material, De Trey Dentsply, Zurich, Switzerland). The second treatment group comprised a total of 32 RMGI restorations. Cavity preparations were conditioned with 37% phosphoric acid gel prior to restoration with Vitremer, (3M Dental St Paul, MN 55144) or Vitrebond (3M Dental St Paul, MN 55144). The third group comprised 32 cavities restored with EBR. The enamel of cavity preparations were conditioned as before, then rinsed with water, except these were primed with XR Primer followed by two coatings of

Table 1: *Restorative Materials*

| Material Type | Restorative Material | Number of Teeth |
|---|---|---|
| Zinc Oxide Euegnol | Intermediate Restorative Material<br>Zinc Oxide Euegnol | 4<br>7 |
| Resin-modified glass ionomer | Vitremer<br>Vitrebond | 16 |
| Enamel bonded resin | XR Bond + Herculite XR | 32 |
| Adhesive bonded composite | Scotchbond + Silux<br>Scotchprep + Silux<br>Gluma Bond + Lumifor<br>Syntac + Heliomar | 35<br>30<br>32<br>30 |

Table 2: *Percentage (numbers) of Cavities Showing Different Grades of Inflammation in the Absence and Presence of Bacteria*

| Material | Total | | Inflammatory Activity | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Slight | | Moderate | | Severe | |
| | - bact | + bact | - bact | + bact | - bact | + bact | - bact | + bact |
| Zinc Oxide Eugenol | 100% (n=11) | 0% (n=0) | 100% (n=10) | 0% (n=0) | 100% (n = 1) | 0 % (n = 0) | 0 % (n = 0) | 0 % (n = 0) |
| Resin Modified Glass Ionomer | 100% (n=32) | 0% (n=0) | 100% (n=14) | 0% (n=0) | 100% (n = 18) | 0 % (n = 0) | 0 % (n = 0) | 0 % (n = 0) |
| Enamel Bonding Resin | 78% (n=25) | 22% (n=7) | 91% (n=10) | 9% (n=1) | 79% (n = 15) | 21 % (n = 4) | 0 % (n = 0) | 100% (n = 2) |
| Adhesive Bonded Composite | 90% (n=114) | 10% (n=13) | 95% (n=42) | 5% (n=2) | 88% (n=61) | 12% (n=8) | 79% (n=11) | 21% (n=3) |

XR bond (Kerr, Romulus, MI) adhesive applied for 30 seconds prior to filling with Herculite XR (Kerr, Romulus, MI). The fourth group consisted of 127 adhesive bonded composite (ABC) cavity restorations that were placed as follows: light curing resin composite (Silux, 3M Dental, St Paul, MN 55144) was placed with Scotchbond adhesive primer in 35 cavity preparations (3M Dental, St Paul, MN 55144) or Scotchprep in 30 cavity preparations (3M Dental, St Paul, MN 55144) following the acid etching of cavity walls using 37% phosphoric acid gel for 60 seconds. In addition, 32 cavities were restored with Lumifor resin (Bayer Dental, Leverkusen, Germany) placed with Gluma (Bayer Dental, Leverkusen, Germany), as well as 30 cavities restored with Heliomolar resin (Vivadent, Schann, Liechtenstein) placed with Syntac (Vivadent, Schann, Liechtenstein).

Extracted teeth were examined histomorphometrically under light microscopy using previously published criteria (Murray & others, 2000a,b). Briefly, 5 micron tooth sections were stained with haematoxylin and eosin and the remaining dentin thickness (RDT) of cavity restorations was measured at 100x magnification using a grid eyepiece graticule. Bacterial contamination of the restorations was assessed using the Brown-Brenn procedure (Lille & Fullmer, 1976) for the presence of gram positive and negative micro-organisms. The observed numbers of micro-organisms were categorized as none, some, medium or extensive, according to numbers of bacteria detected, as described by Franquin & Brouillet (1988). Pulpal inflammation was categorized according to Federation Dentaire International standards (1980) and previously published criteria (Mjör, 1985, 1990; Murray & others, 2000a,b). A slight inflammatory response manifested as the presence of hemorrhage and circulatory stasis in the subodontoblastic region at the base of the preparation floor, but with an underlying normal odontoblast cell distribution. A moderate response was characterized by localized hyperemia or hemorrhage containing scattered leukocytes of the acute or chronic series, depending on the postoperative interval, as well as a reduction in the uniform odontoblast cell layer into an irregular layer with signs of incipient inflammation. A severe response indicated the complete disintegration of the odontoblasts, microabscess formation related to the preparation floor and pulpitis-type edema in the pulp core. Therefore, inflammation was assessed on a continuous semi-quantative scale according to the severity of pulp reactions. Although this data was continuous in nature, it was not on a numerical scale, consequently it was converted to a numerical scale as follows (Absent/slight=0), (Moderate=1) and (Severe=2) for ease of presentation. The raw numerical data was examined using Analysis of Variance (ANOVA), where appropriate, and Spearman's Rho correlation coefficient was used for other types of statistical analysis (StatView software, SAS Inc).

## RESULTS

### Cavity Restoration Materials

The severity of pulpal inflammatory activity appeared to be related to both the selection of cavity restoration material and the presence of bacterial infection (Spearman's Rho $p$=0.0001). Cavities restored with ZOE and RMGI were found to effectively exclude bacteria (Table 2), and the range of the pulpal inflammatory response was from slight to moderate in the absence of bacteria (Figure 1). EBR and ABC restorations seemed to cause a greater severity of inflammatory activity in the absence of bacteria than ZOE and RMGI. EBR and ABC materials were also less effective at excluding bacteria (Table 2), and once infected, the presence of bacteria appeared to increase the severity

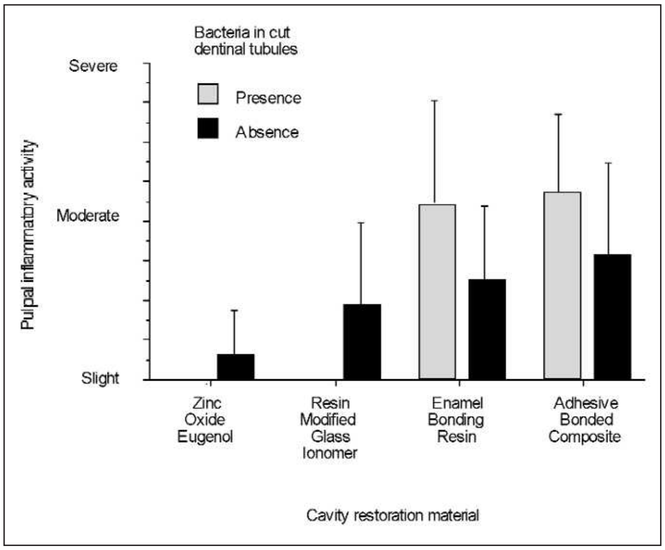


Figure 1. *Pulpal inflammatory activity associated with restorative materials.*

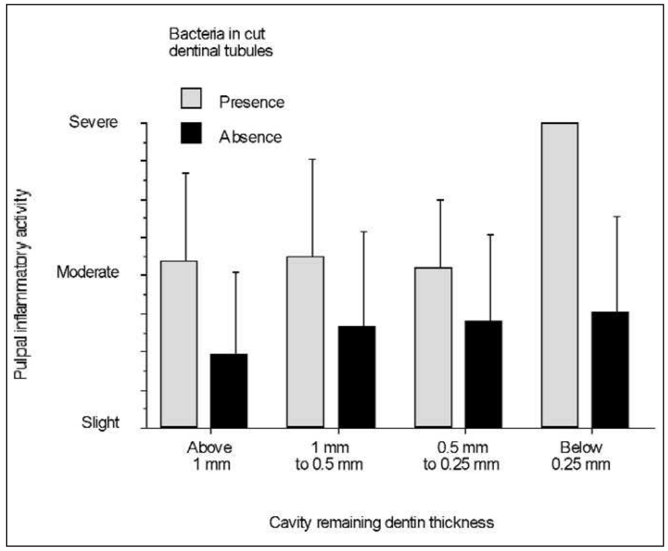


Figure 2. *Pulpal inflammatory activity associated with cavity remaining dentin thickness.*

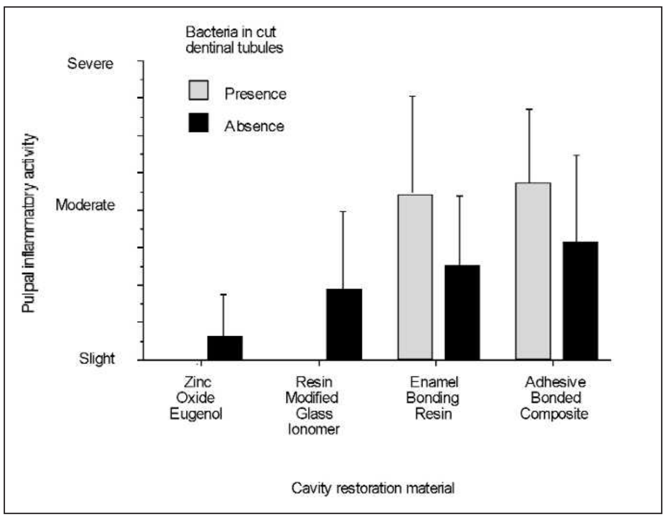


Figure 3. *Levels of pulpal inflammatory activity associated with the time elapsed since surgery.*

of pulpal inflammation (Figure 1). No bacteria were detected in ZOE or RMGI restorations, however, 22% of EBR and 10% of ABC restorations became infected (Table 2).

### Cavity Remaining Dentin Thickness

The cavity RDT was found to be an important factor mediating pulpal inflammatory activity (ANOVA $p$=0.0037), particularly when the RDT was reduced below 0.25 mm (Figure 2). The presence of bacteria in cavity restorations with a RDT below 0.25 mm stimulated severe forms of pulpal inflammatory activity.

In the absence of bacteria, similar cavity preparations appeared to stimulate more moderate pulpal inflammation (Figure 2). Some inflammatory activity was observed in the absence of bacteria with greater cavity RDTs, however, the presence of bacteria always increased the mean grade of pulpal inflammation, regardless of the RDT (Figure 2).

### Time Elapsed Since Surgery

The severity of the pulpal inflammatory response appeared to be time-dependent (ANOVA $p$=0.0366). The severity of pulpal inflammatory activity peaked between 13 and 20 weeks in the presence of bacteria and between 4 and 12 weeks in the absence of bacteria (Figure 3). Pulpal inflammation in the absence of bacteria seemed to be largely resolved once 30 weeks had elapsed but not when bacteria were present within the cavity restorations (Figure 3). The least difference between grades of inflammation in the absence and presence of bacteria was less than three weeks following surgery. At all time intervals large variations in the mean grades of inflammatory activity existed.

### Experimental Controls

The cavity RDT was examined between cavity preparations to test for any skew in the data between particular materials or time periods. ANOVA tests established no evidence of confounding variables at the $p$=0.05 significance level: RDT versus cavity restoration materials ($p$=0.5051), weeks elapsed following surgery ($p$=0.682).

## DISCUSSION

Previous investigations into pulpal inflammatory activity have clearly shown the therapeutic benefits of excluding bacteria from cavity restorations; this has culminated in the development of new restorative materials and placement techniques that more completely seal with the tooth structure. These developments have benefited patients over many years. Human postoperative pulpal repair activity (Murray & others, 2000a) and pulp cell survival (Murray & others, 2000b) have been recently characterized, and the interaction between cavity preparation and restoration variables causing pulp pathology has been shown. However, evidence is lacking that explains how the variables of cavity RDT, restoration materials and the presence or absence of bacteria act to influence pulpal inflammatory activity. Generally, investigations of inflammation have focused on single factors, most commonly the difference between the placement of different types of restorative materials. Nevertheless, the severity of pulpal inflammatory activity results from the combined effects of all the cavity preparation and restoration events. This explains the authors' attempts to correlate these variables together using a morphometric and ANOVA analytical approach. Examining tissue inflammation can be problematic because it is a dynamic activity which either subsides or increases in severity over time. To overcome this difficulty, 202 restored teeth were examined between 3 and 381 days post-operatively. Cavities were prepared in caries-free teeth to avoid the possibility of including residual caries effects within the data. Currently, there is an ever-expanding range of adhesive systems available to practitioners, and to ensure that the findings of this paper are realistic to the restorative work of as many practitioners as possible, four of the most commonly used products were evaluated.

The increasing severity of pulpal inflammatory activity with a decreasing cavity RDT in the presence and absence of bacteria (Figure 2) agrees with previous investigations (Seltzer & Bender, 1990; Camps & others, 2000). It appears difficult to avoid pulpal necrosis in cases where the RDT is less than 0.25 mm and bacteria have infiltrated the restoration cavity walls (Figure 2). This can be compared to the extent of pulpal inflammation beneath a carious lesion, which depends on the depth of bacterial invasion. With a RDT above 1.1 mm or more, little inflammatory activity was observed, and when bacteria had reached to within 0.5 mm of the pulp, there was a significant increase in the severity of inflammation. The pulpal tissues became acutely inflamed once bacteria had reached the pulp chamber (Reeves & Stanley, 1966).

In agreement with previous studies (Camps & others, 2000), it was observed that with every variable measured, the mean category of pulpal inflammation always increased with the presence of bacteria (Figures 1- 3). Nevertheless, not all pulpal inflammation was associated with bacteria. Varying categories of inflammation were associated with cavity restoration materials (Figure 1) (Table 2), the cavity RDT (Figure 2) and the time elapsed since surgery (Figure 3). In the absence of bacteria and in rank order of severity of inflammatory activity from the least to the greatest, the materials were: ZOE, RMGI, EBR and ABC. The greater inflammatory activity observed with RMGI, EBR and ABC may be partly due to dentin etching prior to placement of these materials. Dentin etching can have dramatic consequences on the inflammation and survival of the pulp (Kitasako & others, 1999).

Although etching can be beneficial for the longevity of restorations, it also increases dentin permeability, which can increase the likelihood of pulp injury by increasing the flow of potential cytotoxins in a pulpward direction (Stanley, Going & Chauncey, 1975). In support of this hypothesis, reductions in the numbers of primary odontoblasts have been reported beneath etched dentin in comparison with unetched dentin (Fujitani, Inokoshi & Hosoda, 1992). However, dentin etching was unlikely to account for all the inflammatory differences observed between RMGI, EBR and ABC materials and ZOE. Variations have been observed in the relative cytotoxic effects of different types of restorative materials on pulp tissue (Murray & others, 2000c). Consequently, differences in the chemical cytotoxic injury to pulp tissue by ZOE (Stanley, 1968; Abou, Hashieh & others, 1998), RMGI (Tarim, Hafez & Cox, 1998), EBR (Gaintantzopoulou, Willis & Kafrawy, 1994) and ABC (Imazato & others, 2000) may be related to these observations of inflammatory activity. Although the presence of bacteria in the restorative material and during the cavity preparation cannot be excluded, in most cases the presence of bacteria is mainly attributed to microleakage.

Placement of ZOE and RMGI was found to prevent bacterial microleakage in 100 percent of cavity restorations for up to one year following surgery (Table 2). This can be attributed to antibacterial activity and direct sealing with dentin cavity walls (Bergenholtz & others, 1982; Tarim & others, 1998). However, placement of EBR and ABC did not seal perfectly to the cavity walls because bacteria were detected in 22% and 10% of these restorations (Table 2). The greater microleakage of bacteria in restorations following use of enamel bonding resin in comparison with GIC agrees with Tsunekawa & others, (1992), but further investigation is required to explain these differences.

The authors have observed that bacterial microleakage in EBR and ABC restorations may provide a partial explanation for the shorter longevity expected with these types of restorations in comparison with conventional RMGI and amalgam restorations (Burke & others, 1999). Attempts have been made to improve the adherence and marginal sealing of adhesive bonded composites (Mertz-Fairhurst, 1998), however, placement of ABC is operator sensitive, and the onset of recurrent caries beneath posterior composites can occur within six months of a cavosurface margin defect (Leinfelder & others, 1989).

This study only investigated inflammation following cavity preparation and restorations in non-carious teeth. The restoration of active carious lesions may be associated with slightly increased levels of inflammatory activity due to pulp responses to the initial lesion. These findings provide compelling evidence to encourage further research into improving placement techniques and materials for EBR and ABC restorations since they are not as effective as ZOE and RMGI materials in preventing bacterial microleakage, and in doing so, minimizing pulpal inflammation. When this has been achieved, current thinking may shift from treating pulpal inflammation as a postoperative complication that arises from time to time to an avoidable and controllable complication.

## CONCLUSIONS

Cavity preparation and restoration with dental materials can stimulate pulp inflammatory activity to a moderate degree. When bacteria infiltrated EBR and ABC restorations, the mean category of inflammatory activity increased slightly and severe inflammation was observed when the RDT was less than 0.25 mm. In the absence of bacteria, pulp inflammatory activity was resolved within 30 weeks following surgery. When clinical considerations allow, these findings suggest the following: severe inflammatory activity and the possibility of recurrent complications may be avoided by placing ZOE and RMGI in preference to EBR and ABC restoration types, and maximizing the remaining dentin thickness of preparations. Signs of pulp inflammation can expect to be resolved within 30 weeks following surgery, in the absence of infection and complications. Increases in the expected severity of inflammatory activity, or prolonged inflammatory activity and associated hypersensitivity, provides an indicator of pulp complications, particularly an early warning of bacterial microleakage.

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Laboratory Research

# Comparative Wear Resistance of Reinforced Glass Ionomer Restorative Materials

AUJ Yap • JCM Teo • SH Teoh



### Clinical Relevance

Fuji IX GP FAST may serve as a potential substitute for composites in low occlusal stress situations where fluoride release is desirable and aesthetic requirements are not high.

## SUMMARY

**This study investigated the wear resistance of three restorative reinforced glass ionomer cements (Fuji IX GP FAST [FJ], Miracle Mix [MM] and Ketac Silver [KS]). Microfilled (Silux [SX]) and mini-filled (Z100 [ZO]) composites were used for comparison. Six specimens were made for each material. The specimens were conditioned for one week in distilled water at 37ºC and subjected to wear testing at 20 MPa contact stress against SS304 counterbodies using a reciprocal compression-sliding wear instrumentation. Distilled water was used as lubricant. Wear depth (µm) was measured using profilometry every 2,000 cycles up to 10,000 cycles. Results were analyzed using ANOVA/Scheffe's test ($p<0.05$). After 10,000 cycles of wear testing, ranking was as follows: KS>ZO>MM>FJ>SX. Wear ranged from 26.1 µm for SX to 71.5 µm for KS. The wear resistance of KS was significantly lower than FJ, MM and SX at all wear intervals. Although KS had significantly more wear than ZO at 2,000 to 6,000 cycles, no significant difference in wear was observed between these two materials at 8,000 and 10,000 cycles. Sintering of silver particles to glass ionomer cement (KS) did not appear to improve wear resistance. The simple addition of amalgam alloy to glass ionomer may improve wear resistance but results in poor aesthetics (silver-black color). FJ, which relies on improved chemistry instead of metal fillers, showed comparable wear resistance to the composites evaluated and is tooth-colored. It may serve as a potential substitute for composites in low-stress situations where fluoride release is desirable and aesthetic requirements are not high.**

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## INTRODUCTION

Glass ionomer cements were first introduced to the dental profession in the early 1970s as a replacement for silicate cements (Wilson & Kent, 1972). They can be defined as cements that consist of a basic glass and an acidic polymer which sets by an acid-base reaction between these two components (McLean, Nicholson & Wilson, 1994). Glass ionomers possess certain properties that make them useful as filling materials for restorations. These include fluoride release, chemical bonding and similar coefficient of thermal expansion to tooth. They are, however, brittle and exhibit limited mechanical strength and low wear resistance (McLean, 1988). The low wear resistance of glass ionomer cements on occlusal surfaces has been attributed to insufficient strength immediately after placement. Wear resistance of glass ionomer reaches an acceptable level only after the cements have had time to build up a greater degree of strength. This increase in mechanical properties may take weeks or even months to occur (de Gee, 1999). Another factor that may influence wear resistance is their sensitivity to acids (Billington, Williams & Pearson, 1992). Attempts were made to improve cement strength and wear resistance by adding metals to the powder component of glass ionomer cements (Simmons, 1983; McLean & Gasser, 1985). The powder contains fluoroaluminosilicate glass and a silver alloy (Simmons, 1983) or the glass is sintered with silver (McLean & Gasser, 1985). The former product is termed an admixed cement (for example, Miracle Mix; GC Corporation, Tokyo, Japan), while the latter is called a cermet (such as Ketac Silver; ESPE, Seefeld, Germany). Due to the addition of metals, these materials are not tooth-colored.

Highly viscous glass ionomer cements were designed as an alternative to amalgam for posterior preventive restorations (Saito, Tosaki & Hirota, 1999). These high powder:liquid ratio glass ionomers provide a "condensable" feel and are particularly useful for the Atraumatic Restorative Treatment (ART) technique introduced by the World Health Organization for use in developing countries (Frencken & others, 1996). This technique uses hand instruments for caries excavation without rotary instruments, with subsequent restoration using highly viscous glass ionomer cements. The clinical survival rates of ART restorations in field trials have been very promising (Frencken & others, 1996). Highly viscous glass ionomers have been classified as Type II.2 restorative reinforced cements (Mount, 1999) by some manufacturers. They rely on improved chemistry rather than metal inclusions for their enhanced mechanical properties and are therefore tooth-colored.

Fuji IX GP FAST (GC Corporation, Tokyo, Japan) is the latest highly viscous glass ionomer cement to be introduced into the dental market. The manufacturer claims a net setting time of two minutes and a final finishing commencement time of three minutes. This fast setting reaction may result in good wear resistance as the material can theoretically achieve sufficient strength to resist masticatory loads within a shorter time. This study compared the wear resistance of Fuji IX GP FAST with two metal-reinforced glass ionomer cements (Miracle Mix and Ketac Silver) and two composites (Silux Plus and Z100; 3M Dental Products, St Paul, MN 55144) under low, masticatory contact stress.

## METHODS AND MATERIALS

Table 1 shows the shade (where applicable) and lot numbers of the materials used. The restorative materials were placed in the rectangular recesses (8 mm long x 4 mm wide x 2 mm deep) of customized acrylic molds and covered with acetate strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was then placed over the mold and pressure was applied to extrude excess material. The glass ionomer cements were allowed to set for 10 minutes, while the composite restoratives were light polymerized for 40 seconds through the glass slide with a Spectrum Curing Light (Dentsply Inc, Milford, DE 19963) of 420 ± 3 mw/cm$^2$ intensity. As the light tip was placed in contact with the glass slide, a constant distance of 1 mm was

Table 1: *Restorative Materials Used in the Study*

| Material | Manufacturer | Type | Lot Number | Shade |
|---|---|---|---|---|
| Silux Plus | 3M Dental Products, St Paul, MN 55144 | Microfill Composite | 19980106 | Yellow |
| Z100 | 3M Dental Products, St Paul, MN 55144 | Minifill Composite | 19980203 | A2 |
| Fuji IX GP FAST | GC Corporation, Tokyo, Japan | Highly Viscous Glass Ionomer Cement | 9970086 | A2 |
| Miracle Mix | GC Corporation, Tokyo, Japan | Admixed Metal-reinforced Glass Ionomer Cement | 170675 | Not applicable |
| Ketac Silver | ESPE, Seefeld, Germany | Sintered Metal-reinforced Glass Ionomer Cement | 609/069 | Not applicable |

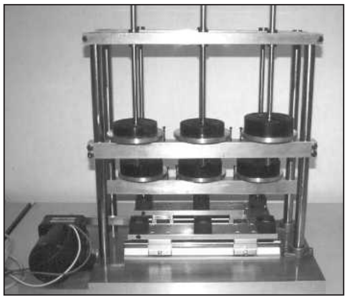

Figure 1. *The reciprocal compression-sliding wear instrumentation.*

achieved between the light source and the composite surface. Immediately after setting/light polymerization, the acetate strips were discarded and the materials stored in distilled water for one week at 37°C. The glass ionomers were not coated with a protective layer of unfilled resin. A total of six wear specimens were made for each restorative material.

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

p=(sxA)/a

where s is the required load, "s" is the contact stress of 20 MPa, "A" is the nominal circular contact area (p$^2$) of 0.79 mm$^2$ and "a" is the gravitational acceleration (9.81 mm/s$^2$) of the load.

Material wear (that is, maximum depth of wear track) was measured using profilometry (Talycontour, Rank Taylor Hobson, Leicester, UK) along the width of the specimens at the center of the wear track, which was localized with markers. A vertical magnification of 200x and a horizontal magnification of 20x were employed for profilometry. The travel length of the stylus was set at 3 mm and the adjacent unworn areas were used as references. Wear measurements were taken at the center of the wear track at every 2,000 cycles up to 10,000 cycles. The wear rate (µm/1,000 cycles) for each wear interval was calculated as follows:

Wear rate = Difference in wear between each 2,000 cycles increment/2

The wear data was analyzed using one-way ANOVA and Scheffe's post-hoc test at significance level 0.05 using a commercial statistics computer software (SPSS Inc, Chicago, IL 60611).

## RESULTS

The mean material wear and wear rate of the various restorative materials are shown in Table 2. The mean cumulative wear is also reflected in Figure 2. Results of statistical analysis are reflected in Table 3.

After 10,000 cycles of wear testing, ranking was as follows: Ketac Silver>Z 100 > Miracle Mix>Fuji IX>Silux. Wear ranged from 26.1 µm for Silux to 71.5 µm for Ketac Silver. The wear resistance of Ketac Silver was significantly lower than Fuji IX, Miracle Mix and Silux at all wear intervals. Although the Ketac Silver had significantly more wear than Z100 at 2,000 to 6,000 cycles, no significant difference in wear was observed between these two materials at 8,000 and 10,000 cycles. No significant difference in wear was observed between Fuji IX, Miracle Mix, Silux and Z100 at all wear intervals.

For all materials, wear rates were the highest for the first 2,000 wear cycles. This ranged from 3.1 to 17.6 µm/1,000 cycles. Ranking of wear rates was as follows: Ketac Silver>Miracle Mix>Z100>Fuji IX>Silux. For all materials, a general decrease in wear rates was observed with an increased number of wear cycles. The range of wear rates after 10,000 cycles of wear testing dropped to 1.7 to 4.7 µm/1,000 cycles. Ranking of wear rates at 10,000 cycles was as follows: Ketac Silver>Z100>Silux>Miracle Mix>Fuji IX.

## DISCUSSION

Both composites and glass ionomers can be considered to be biphasic with one phase embedded in the other. Composites consist of fillers embedded in a polymer resin and glass ionomers consist of unreacted glass particles in a hydrogel matrix. The wear of these materials can be understood by considering the relationship between slurry wear and sliding contact wear. Slurries (suspended food particles) tend to preferentially abrade the softer phase leaving the harder filler/glass particles protruding from the surface. Sliding contact wear results from direct tooth contact during bruxism/mastication and indirect contact through trapped food particles (Adams & Zander, 1964; Mair & others, 1996). During sliding contact wear, the harder filler/glass particles remain intact and transmit the sliding forces to the surrounding matrix, resulting in microcracking and subsequent particle displacement. The latter results in the exposure of the softer matrix phase and wear ensue. Based on the aforementioned information, a stainless steel counter-body was used. A stainless steel counter-body was recommended by McKinney & Wu (1982), as it preferentially wears the softer matrix. Combined with the two-body action of the wear instrumentation,

Table 2: *Mean Wear and Wear Rate for the Various Restorative Materials*

| Cycles | 2000 | 4,000 | 6,000 | 8,000 | 10,000 |
|---|---|---|---|---|---|
| **Mean Wear in µm (Standard Deviation)** | | | | | |
| **Fuji IX** | 10.0 (3.4) | 16.1 (3.3) | 20.1 (4.3) | 24.3 (4.3) | 27.9 (4.9) |
| **Miracle Mix** | 12.5 (2.2) | 19.2 (2.9) | 25.7 (5.6) | 29.8 (6.9) | 33.7 (8.0) |
| **Ketac Silver** | 35.2 (16.8) | 46.9 (25.1) | 57.1 (27.0) | 62.2 (29.3) | 71.5 (31.5) |
| **Silux Plus** | 6.2 (2.0) | 11.5 (3.1) | 16.2 (2.7) | 20.6 (3.4) | 26.1 (4.1) |
| **Z100** | 11.8 (2.9) | 20.0 (3.4) | 28.6 (4.6) | 39.6 (6.5) | 46.8 (8.6) |
| **Wear Rate (µm/1,000 Cycles)** | | | | | |
| **Fuji IX** | 5.0 | 3.1 | 2.0 | 2.1 | 1.7 |
| **Miracle Mix** | 6.3 | 3.3 | 3.3 | 2.1 | 1.9 |
| **Ketac Silver** | 17.6 | 5.9 | 5.1 | 2.5 | 4.7 |
| **Silux Plus** | 3.1 | 2.6 | 2.3 | 2.2 | 2.8 |
| **Z100** | 5.9 | 4.1 | 4.3 | 5.5 | 3.6 |

Table 3: *Results of Statistical Analysis*

| Cycles | Differences |
|---|---|
| 2,000 | Ketac Silver > all |
| 4,000 | Ketac Silver > all |
| 6,000 | Ketac Silver > all |
| 8,000 | Ketac Silver > Silux, Fuji IX and Miracle Mix |
| 10,000 | Ketac Silver > Silux, Fuji IX and Miracle Mix |

Results of one-way ANOVA at significance level 0.05. > indicates statistical significance in wear.

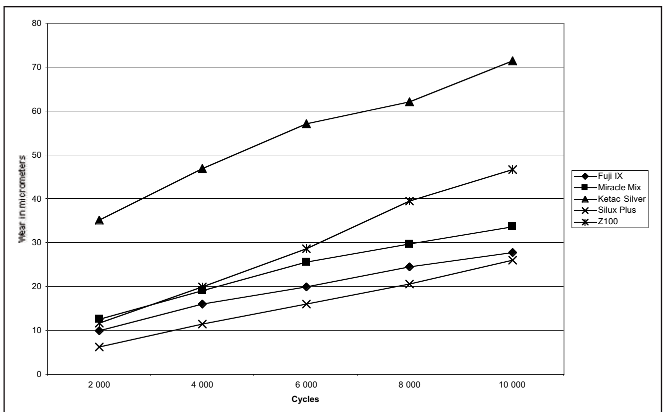


Figure 2. Mean wear of the different restoratives.

they provide for both slurry and sliding wear. The wear patterns attained with stainless steel counter-bodies has been observed clinically on posterior composite restorations (Abel, Leinfelder & Turner, 1983).

Clinical findings suggest that contact stress during mastication and parafunction is an important factor influencing wear of tooth-colored restoratives and opposing tooth structure (Chapman & Nathanson, 1983). Yap & others (2001) has showed that an increase in contact stress enhances the wear of tooth-colored restoratives. For the same material, wear mechanisms vary with different contact stresses. Stress values ranging from 3.9 to 17.3 MPa had been reported during mastication (Anderson, 1956). A 20 MPa stress was therefore selected. During parafunction, (that is, clenching and bruxism) occlusal forces and contact stresses far exceed those used during mastication (Clark, Townsend & Carey, 1984). Water was chosen as the storage and wear medium as it has been shown to produce the greatest wear (Yap & others, 2000). The acetate finish ensured the smoothest finish possible for the restorative materials and prevented dehydration of the glass ionomers (Yap, Lye & Sau, 1997). As the setting time of the glass ionomers ranged from two to six minutes, a 10 minute setting time was used for standardization purposes.

Wear resistance of Ketac Silver was significantly lower than Fuji IX, Miracle Mix and Silux at all wear intervals. Ketac Silver also had significantly more wear than Z100 after wear testing for 2,000 to 6,000 cycles. The sintering of silver particles to glass ionomer cement did not appear to improve wear resistance. This finding is in agreement with that of Fross, Seppa & Lappalainen (1991). They found that the cermet cement did not exhibit better wear resistance than conventional unreinforced glass ionomers. There are two other possible hypotheses for significantly poorer wear performance of Ketac Silver. First, Ketac Silver may be more sensitive to the effects of early moisture exposure. Glass ionomers are generally hydrolytically unstable during initial stages of setting when calcium salts are being formed (Crisp, Lewis & Wilson, 1975). During this period the cements can dehydrate when exposed to air. Alternatively, if exposed to moisture, the cements can uptake water and essential ions can be eluted. Both water loss and uptake in the early stages of the setting reaction results in the reduction of mechanical properties (Causten, 1982). With time, the calcium ions are slowly displaced by aluminum ions, which further enhance the cohesion of the matrix and improve mechanical properties. No protective layer of unfilled resin was applied to any of the glass ionomers, as the worst-case scenario was desired. In addition, the authors wished to validate the "fast-set" claims of Fuji IX. The latter should theoretically decrease early moisture sensitivity and increase the rate of maturation and improve mechanical properties. The speed of the setting reaction can be increased by removing excess calcium ions from the surfaces of the glass particles during the manufacturing process, including tartaric acid in the liquid component and decreasing the glass particle size. Differences in formulation and manufacturing process may explain the better wear performance of cements from GC compared to Ketac Silver.

Another possible reason for the poorer wear performance of Ketac Silver compared to Fuji IX and Miracle Mix may be its susceptibility to the effects of hydrolysis. This was evidenced by the high wear rates observed for Ketac Silver during the first 2,000 cycles of wear testing. The composite resins investigated are also susceptible to the effects of hydrolysis (Yap, Teoh & Tan, 2000). Mean three-body wear increased from 1.88 to 14.80 µm for Silux and from 0.66 to 9.20 µm for Z100 with one week exposure to distilled water at 37ºC. This conditioning regimen was also used in this study. The one-week period also allows for greater maturation of glass ionomers prior to wear testing. The wear resistance of glass ionomers had been shown to improve over time (de Gee & others, 1996). A large standard deviation was observed for the wear of Ketac Silver, and the effects of early moisture sensitivity and hydrolysis by water can account for this. In either case, the extent of damage and homogeneity of the surfaces cannot be predicted or controlled. The lack of statistical significance in wear between Ketac Silver and Z100 was largely due to the high standard deviation and the consistently higher wear rates with Z100. No statistical difference in wear was observed between Fuji IX/Miracle Mix and the composites at all cyclic intervals. Wear performance may, however, change with the increased number of wear cycles due to fatigue wear mechanisms, and this warrants further investigations.

For all materials, wear rates were highest during the first 2,000 cycles and generally decreased with increasing wear cycles. This was expected as the acetate finish results in a surface that was matrix-rich and less wear resistant. Ranking from lowest to highest wear rates for the first 2,000 cycles was: Silux (3.1)<Fuji IX(5.0)<Z100(5.9)<Miracle Mix (6.3)<Ketac Silver (17.6). The mean wear rate (µm/1,000 cycles) for 4,000 to 10,000 cycles, in increasing order, were as follows: Fuji IX (2.2)<Silux (2.5)<Miracle Mix (2.7)<Z100 (4.4)<Ketac Silver (4.6). The difference in wear rate ranking is obvious and may be accounted for by the change in surface constituents between the first 2,000 and subsequent wear cycles. The good wear resistance of Miracle Mix may be attributed to the lubricating effect of the silver alloy particles and increased strength and fatigue resistance from metal-reinforcement (Williams, Billington & Pearson, 1992; Nakajima & others, 1996). Although no significant difference in wear existed between Fuji IX and Miracle Mix, Fuji IX offers better aesthetics as it is tooth-colored. It is, however, less translucent compared to composite resins. Fuji IX GP FAST showed comparable wear resistance to the composites evaluated and may serve as a potential substitute for composites in low-stress situations where fluoride release is desirable and aesthetic requirements are not high.

## CONCLUSIONS

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

1. No significant difference in wear was observed between the materials tested at all wear intervals.
2. For all materials, wear rates were highest for the first 2,000 cycles and generally decreased with increase number of wear cycles.
3. Wear ranking after 2,000 cycles was: Ketac Silver>Miracle Mix>Z100>Fuji IX > Silux.
4. Wear ranking after 10,000 cycles was: Ketac Silver>Z100>Miracle Mix>Fuji IX>Silux.

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# Influence of Thermal Cycling on OCA Wear of Composite Restoratives

AUJ Yap • KEC Wee
SH Teoh • CL Chew

**Clinical Relevance**

Thermal cycling may have potentially detrimental consequences on the long-term clinical durability of some composites.



## SUMMARY

**This study investigated the effects of thermal cycling on wear of four commercial composite resins (Silux, Z100, Ariston and Surefil). Specimens of each material were divided into three treatment groups comprising a control and two different thermal cycling regimes. Control specimens were stored in distilled water at 35ºC for 178 hours. Thermal cycled specimens were stored in distilled water at 35ºC for 173 hours and subjected to five hours (300 cycles) of a thermal cycling regime consisting of the cycle ABAC, where A and B represent the fixed temperatures of 35ºC (28 seconds) and 15ºC (two seconds) and C, depending on the treatment group, was either 45ºC or 60ºC (two seconds). All specimens were subsequently subjected to wear testing at 20 MPa contact stress against SS304 counterbodies with distilled water as the lubricant. Wear depth (µm; n=6) was measured using profilometry every 2,000 cycles up to 10,000 cycles. Results were analyzed using ANOVA/Scheffe's test ($p<0.05$). The effect of thermal cycling on wear was material-dependent. The wear of Silux and Z100 were not significantly affected by thermal cycling. Thermal cycling of Ariston at an upper temperature of 60ºC significantly decreased wear resistance. Thermal cycling affected only the early wear resistance of Surefil.**

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## INTRODUCTION

Composites may be defined as three-dimensional combinations of at least two chemically different materials with a distinct interface (Phillips, 1981). Dental composites consist of a resin matrix (organic phase), inorganic filler particles (dispersed phase), filler-matrix coupling agent (interface) and minor additions including polymerization initiators, stabilizers and coloring pigments. Significant advancements in composite formulations have greatly decreased the extent of clinical wear. In conservative restorations exposed to minimal direct stress, the wear of many current composites is nearly equivalent to that of amalgam (Leinfelder & others, 1986; Willems & others, 1993; Bayne, Heymann & Swift, 1994). Wear under stress-bearing or occlusal contact areas may, however, be three to five times greater than that in contact free areas (Lutz & others, 1984; Willems & others, 1993). Occlusal contact area (OCA) wear is the summation of sliding wear caused by direct tooth contact during parafunction (bruxism) and indirect tooth contact during function (closed phase of mastication) (Mair & others, 1996). If the amount of OCA wear is of sufficient magnitude, appreciable changes may develop in functional occlusion.

During both function and parafunction generated stresses are transmitted through the rigid and brittle fillers into the more flexible and ductile resin matrix. Stress concentrations at the filler-resin interface may contribute to wear, as failure at this interface leads to filler dislodgement and exposure of the resin matrix that wears away rapidly (Kusy & Leinfleder, 1977). Such stress concentrations may be generated by water sorption, leakage of filler constituents, polymerization shrinkage and thermomechanical cycling (Kusy & Leinfelder, 1977; Dickson, 1979; Söderholm, 1983). Although the effects of thermal cycling on tracer penetration and shear bond strength tests of dental materials has been widely investigated (Gale & Darvell, 1999), studies regarding its effects on wear are limited. Mair (1991) and Chadwick (1994) found that certain composites might experience increased wear when subjected to different thermal-cycling regimens. Both studies involved the use of extended dwell times (90 seconds to 2.25 minutes) at each of the extremes in temperature. The relevance of this to the oral environment is questionable as transient thermal changes are of greater significance intraorally (Pearson & others, 1980). After assessing the reports describing temperature changes of teeth *in vivo* and an analysis of 130 *in vitro* studies involving thermal cycling of teeth, a clinically relevant thermal cycling regimen was suggested by Gale & Darvell (1999).

This study investigated the effects of thermal cycling/cycling on the OCA wear of four commercial composite restoratives based on the regimen advocated by Gale & Darvell (1999). The OCA wear resistance of the different composites was also compared.

## METHODS AND MATERIALS

Table 1 shows the technical profiles of the composites evaluated. They include a micro-filled (Silux Plus), two mini-filled (Z100 and Surefil) and a midi-filled (Ariston pHc) composite. The composites were placed in the rectangular recesses (8 mm long, 4 mm wide and 2 mm deep) of customized acrylic molds and covered with acetate strips (Hawe-Neos Dental, Bioggio, Switzerland). A glass slide was placed over the acetate strip and pressure was applied to extrude excess material. The composites were then light cured according to the manufacturers' cure time through the glass

Table 1: *Technical Profiles of the Composites Evaluated*

| Material | Manufacturer | Type Cure Time | Polymer | Fillers | Filler Size (μm) | Filler Content (% by volume) |
|---|---|---|---|---|---|---|
| Silux Plus (Lot #19980106) | 3M Dental Products, St Paul, MN 55144 | Microfill 40 seconds | BisGMA TEGDMA | Silica | 0.04 (mean) | 40 |
| Z100 (Lot #19980203) | 3M Dental Products, St Paul, MN 55144 | Minifill 40 seconds | BisGMA TEGDMA | Zirconia Silica | 0.5 – 0.7 (mean) | 66 |
| Ariston pHc (Lot #A06719) | Vivadent Schaan, Liechtenstein | Midifill 40 seconds | BisGMA UDMA TEGDMA | Ba-Al-Fluorosilicate glass Alkaline glass Silica Ytterbium Trifluoride | 1.3 (mean) | 59 |
| Surefil (Lot #980709) | Dentsply-Caulk Milford, DE 19963 | Minifill 40 seconds | Urethane-modified BisGMA | Ba-Boron-Fluorosilicate glass Silica | 0.8 (mean) | 65 |

BisGMA = Bisphenol-A-dimethacrylate
TEDGMA = Triethylene glycol dimethacrylate
UMDA = Urethane dimethacrylate

Composite classification based upon that reported by Ferracane (1995).

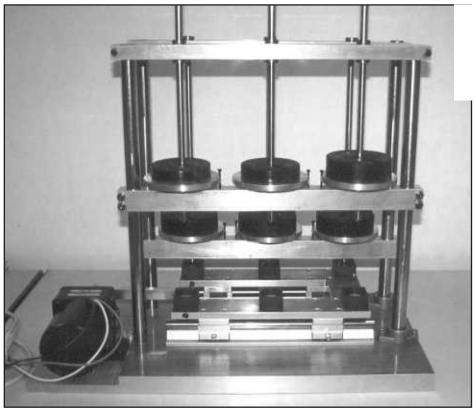

Figure 1. *The reciprocal compression-sliding wear instrumentation used.*

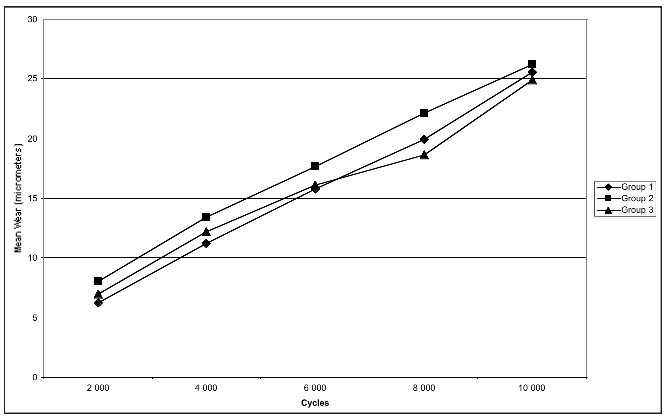


Figure 2. *Mean wear of Silux for the different treatment groups.*

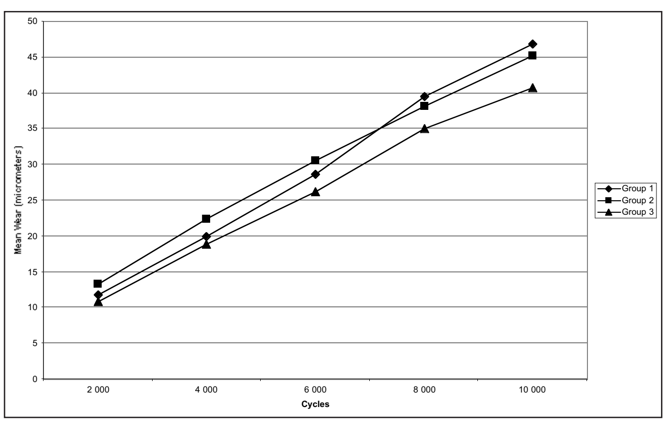


Figure 3. *Mean wear of Z100 for the different treatment groups.*

slide/acetate strip with a curing light (Spectrum, Dentsply Inc, Milford, DE 19963). The intensity of the light source was checked with a radiometer (Cure Rite, EFOS Inc, Ontario, Canada) to ensure constant output.

A total of 18 specimens was made for each composite. The composite specimens were randomly divided into three treatment groups of six specimens each. Specimens in Group 1 (control) were stored in distilled water at 35ºC for 178 hours. Group 2 (cycled 45ºC) specimens were stored in distilled water at 35ºC for 173 hours and subjected to five hours (300 cycles) of thermal cycling with an upper temperature of 45ºC. The specimens in Group 3 (cycled 60ºC) were also stored in distilled water at 35ºC for 173 hours and subjected to five hours (300 cycles) of thermal cycling but with an upper temperature of 60ºC. One thermal cycle consisted of the cycle ABAC. The temperatures of the water in containers A and B were fixed at 35ºC and 15ºC, respectively. The temperature of the water in container C was either 45ºC or 60ºC depending on the treatment group. Dwell (immersion) time in container A was 28 seconds, while the dwell time in containers B and C was two seconds. The total time for each thermal cycle was, therefore, one minute.

After treatment the specimens were wear-tested using a reciprocal compression-sliding wear instrumentation (Figure 1) in which the specimens were moved back and forth against a loaded counter-body. The apparatus utilized a crank-and-slider mechanism, whereby the rotary action of an induction motor was translated to linear motion of the sliding platform. One complete circle drawn by the crank translated to one complete horizontal motion of the platform, comprising a forward stroke of 3 mm and a backward stroke of 3 mm. Details of the wear instrumentation had been described in a previous paper (Yap & others, 2001). The composites were subjected to wear testing against circular, flat-ended AISI SS304 stainless steel abrading counterbodies of 1 mm diameter at 100 cycles/minute with distilled water as lubricant at 23 ± 2ºC. Prior to usage, the stainless steel abrading counterbodies were finished with a series of sandpapers from 600 to 1200 grit to standardize the contact surfaces. A constant stress of 20 MPa was maintained throughout the entire experiment with the use of a 1.6 kg load based on the formula:

$$p = (s \times A)/a$$

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

Composite wear (the maximum depth of wear track) was measured using profilometry (Talycontour, Rank Taylor Hobson, Leicester, UK) along the width of the specimens at the center of the wear track, which was localized with markers. A vertical magnification of 200x and a horizontal magnification of 20x was employed for profilometry. The travel length of the stylus was set at 3 mm and the adjacent unworn areas were used as references. Wear measurements were taken at the center of the wear track at every 10 cycles up to 100 cycles and subsequently at every 2,000 cycles up to 10,000 cycles.

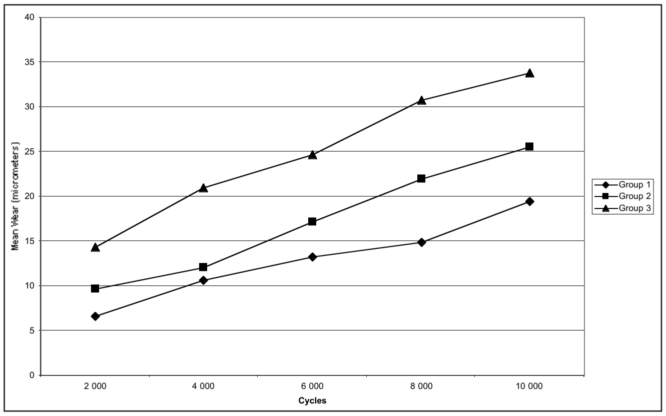


Figure 4. *Mean wear of Ariston pHc for the different treatment groups.*

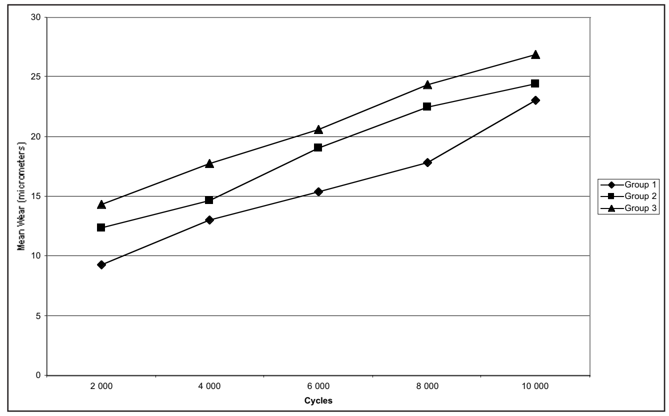


Figure 5. *Mean wear of Surefil for the different treatment groups.*

Table 2: *Mean Composite Wear (μm) for the Different Treatment Groups*

| Material | Treatment Group | Number of Wear Cycles 2,000 | 4,000 | 6,000 | 8,000 | 10,000 |
|---|---|---|---|---|---|---|
| Silux | Group 1 | 6.31 (2.02) | 11.29 (3.10) | 15.78 (2.86) | 19.97 (3.73) | 25.59 (4.23) |
| | Group 2 | 8.07 (0.67) | 13.48 (0.69) | 17.66 (1.03) | 22.14 (1.13) | 26.28 (1.71) |
| | Group 3 | 7.04 (1.40) | 12.23 (1.48) | 16.13 (2.00) | 18.68 (2.10) | 24.93 (2.24) |
| Z100 | Group 1 | 11.77 (2.85) | 20.04 (3.38) | 28.62 (4.61) | 39.60 (6.49) | 46.83 (8.56) |
| | Group 2 | 13.26 (3.95) | 22.44 (4.21) | 30.62 (6.20) | 38.16 (8.08) | 45.28 (8.29) |
| | Group 3 | 10.91 (2.15) | 18.94 (2.53) | 26.29 ((2.36) | 35.08 (1.46) | 40.81 (1.91) |
| Ariston pHc | Group 1 | 6.68 (1.46) | 10.64 (3.10) | 13.29 (3.93) | 14.90 (3.53) | 19.48 (4.70) |
| | Group 2 | 9.64 (3.46) | 12.08 (3.31) | 17.18 (4.93) | 21.93 (4.68) | 25.54 (4.79) |
| | Group 3 | 14.31 (4.24) | 20.98 (4.60) | 24.68 (4.19) | 30.81 (5.59) | 33.76 (4.67) |
| Surefil | Group 1 | 9.30 (1.22) | 13.02 (3.07) | 15.43 (4.42) | 17.87 (5.83) | 23.10 (8.97) |
| | Group 2 | 12.36 (1.42) | 14.65 (0.89) | 19.09 (3.08) | 22.46 (2.31) | 24.49 (1.71) |
| | Group 3 | 14.36 (1.53) | 17.78 (1.52) | 20.60 (2.75) | 24.38 (2.32) | 26.92 (3.02) |

Group 1 = Control; Group 2 = Cycled 45ºC; Group 3 = Cycled 60ºC.

A significance level of 0.05 was used for all statistical analysis. Two-way analysis of variance (ANOVA) was performed on wear data with composite material and treatment groups as main effects. Post-hoc Scheffe's tested for differences among means (SPSS Inc, Chicago, IL 60611). One-way ANOVA was performed for each material to determine the effects of thermal cycling on composite wear. One-way ANOVA was used to compare the OCA wear resistance between composites after the different treatments and 10,000 cycles of wear testing.

## RESULTS

The mean composite wear for the different treatment groups is shown in Table 2 and Figures 2-5. Table 3 displays the results of the statistical analysis. Two-way ANOVA showed significant interaction ($p$=0.002) between materials and treatment group. The effects of thermal cycling on wear was therefore material-dependent.

No wear was detected for all material and treatment group combinations during the first 100 cycles. At all

Table 3: *Results of Statistical Analysis*

| Cycles | Material | Significance |
|---|---|---|
| **2,000** | **Silux** | NS |
| | **Z100** | NS |
| | **Ariston pHc** | Group 3 > Group 1 |
| | **Surefil** | Group 3 & Group 2 > Group 1 |
| **4,000** | **Silux** | NS |
| | **Z100** | NS |
| | **Ariston pHc** | Group 3 > Group 1 & Group 2 |
| | **Surefil** | Group 3 > Group 1 |
| **6,000** | **Silux** | NS |
| | **Z100** | NS |
| | **Ariston pHc** | Group 3 > Group 1 & Group 2 |
| | **Surefil** | NS |
| **8,000** | **Silux** | NS |
| | **Z100** | NS |
| | **Ariston pHc** | Group 3 > Group 1 & Group 2 |
| | **Surefil** | NS |
| **10,000** | **Silux** | NS |
| | **Z100** | NS |
| | **Ariston pHc** | Group 3 > Group 1 & Group 2 |
| | **Surefil** | NS |

*Results of one-way ANOVA and Scheffe's test (p<0.05). NS indicates no statistical significance and > indicates statistical significance. Group 1 = Control; Group 2 = Cycled 45ºC; Group 3 = Cycled 60ºC.*

wear cycles (2,000 to 10,000), no significant difference in wear was observed between the control and thermal cycled groups for Silux and Z100. Therefore, the OCA wear of Silux and Z100 was not affected by thermal cycling. After 2,000 cycles of wear testing, Group 3 (cycled 60ºC) Ariston specimens had significantly more wear than the control group (Group 1). From 4,000 to 10,000 cycles, wear results were identical. Specimens in Group 3 had significantly more wear than specimens in Groups 1 (control) and 2 (cycled 45ºC). Thermal cycling at an upper temperature of 60ºC significantly decreased wear resistance of Ariston. At 2,000 cycles, thermal cycled Surefil specimens (Groups 2 and 3) had significantly more wear than specimens that were not (Group 1). At 4,000 cycles, only Group 3 (cycled 60ºC) specimens had significantly more wear than the control group (Group 1). From 6,000 cycles to 10,000 cycles, no significant difference in wear was observed between thermal cycled (Groups 2 and 3) and non-thermal cycled groups (Group 1). Thermal cycling may therefore have some detrimental effects on the early wear resistance of Surefil.

After 10,000 cycles of wear testing, Z100 experienced significantly more wear than Silux, Ariston and Surefil for all treatment groups. No significant difference in wear was observed among Silux, Ariston and Surefil for Groups 1 (control) and 2 (cycled 45ºC). When thermal cycled at an upper temperature of 60ºC (Group 3), Ariston experienced significantly more wear than Silux and Surefil.

## DISCUSSION

Intra-oral temperature changes may be produced by routine drinking (Palmer, Barco & Billy, 1992), eating (Crabtree & Atkinson, 1955) and breathing (Boehm, 1972). Thermal stress may be pathogenic in two ways. First, mechanical stresses generated by differences in coefficient of thermal expansion can result in bond failure at the tooth-restorative interface (Eakle 1986; Crim & García-Godoy, 1987). Then, the changing gap dimensions are associated with gap volume changes that pump pathogenic oral fluids in and out of the gaps (Nelsen, Wolcott & Paffenbarger, 1952; Torstenson & Brannström, 1988). The physical properties of composite resins may also be affected by thermal stresses (Lloyd, 1982). A physical parameter thought to be associated with wear resistance is the stress intensification factor ($K_{IC}$) (Truong & Tyas, 1988). $K_{IC}$ is an inherent material property and can indicate the resistance to fracture caused by the propagation of cracks of flaws. Although the work of Mair & Vowles (1989) showed that thermal cycling had no effect on $K_{IC}$values of composites, Mair (1991) found that subjecting composites to a thermal cycling regimen produced an increase in wear rate. The discrepancy in results may be partially explained by the different thermal cycling regimens used in each investigation and highlights the need for standardization of thermal cycling regimens.

The thermal cycling regimen advocated by Gale & Darvell (1999) was 35ºC (28 seconds), 15ºC (two seconds), 35ºC (28 seconds) and 45ºC (two seconds). This clinically relevant thermal cycling regimen was derived from *in vivo* information and was suggested as the benchmark standard for all laboratory testing of dental restorations. Most *in vivo* studies measuring temperatures at the outer surface of teeth involved the use of thermocouples (Peterson, Phillips & Swartz, 1966; Palmer & others, 1992) or thermistors (Plant, Jones & Darvell, 1974) during the drinking of hot and cold liquids. Several confounding factors had been identified, including large temperature variations in different parts of the mouth, the effects of fluid volume/exposure time on temperature changes and differences in tolerable temperature range between subjects. The extremes in temperature were fixed at 15ºC and 45ºC, as they were the lowest/highest comfortable temperatures reported from *in vivo* studies (Gale & Darvell, 1999). Plant & others (1974) determined that fluids were too hot to sip above 68ºC but subjects could sip them with discomfort between 60 and 68ºC. Subjects could also drink them, although relatively hot, between 55 to 60ºC, and they could drink them freely in large amounts between 50ºC and 55ºC. The latter cup temperature (55ºC) produced the maximum comfortable tooth surface temperature of 47ºC (Plant & others, 1974). As an upper temperature limit of 60ºC had been shown to increase wear of composites (Montes & Draughn, 1986; Mair, 1991), an upper limit of 60ºC was also included in this study. Stainless steel counterbodies were used for reasons given by McKinney & Wu (1982). In addition, the wear patterns associated with the use of stainless steel counterbodies were observed clinically on posterior composite restorations (Abel, Leinfelder & Turner, 1983). An acetate finish, the smoothest for tooth-colored restoratives (Yap, Lye & Sau, 1997), provided for a worse-case scenario where a polymer-rich surface is exposed and avoided the discrepancies associated with rotary finishing/polishing procedures. The polymer-rich layer will probably be removed within a few passes of the counterbody.

Composite resins are known to leach filler constituents by the process of stress corrosion (Söderholm, 1983). When immersed in water, the resin matrix swells and radial tensile stresses are introduced at the silicate filler-resin interfaces, thereby straining the Si-O-Si bonds in the fillers. The high energy levels resulting from the strained Si-O-Si bonds make the fillers more susceptible to stress corrosion attack, resulting in complete and partial debonding of the fillers at the surface layers. It was therefore prudent that the contact time with water was standardized for all treatment groups. The total contact time with water was 178 hours for both the control and thermal cycled groups (173 hours storage in water followed by five hours of thermal cycling in water). Mair (1989) studied the surface permeability and degradation of dental composites resulting from oral temperature changes. He found that rapid temperature changes resulted in the formation of microcracks, while slow rates of change increased the depth and rate of diffusion of silver nitrate. The rapid change in temperatures employed in this thermal cycling regimen, which occurs routinely *in vivo* (Spierings & others, 1987), could cause microcracking as a result of surface dimensional changes (Mair, 1991). The possible progression of microcracks compounded with complete/partial debonding of fillers arising from water exposure may result in increased wear. As the effects of thermal cycling are expected to predominantly appear in the surface layers, wear was assessed every 10 cycles for the first 100 cycles. However, no wear was detected for all material and treatment group combinations during the first 100 cycles.

The effects of thermal cycling on wear was found to be composite-dependent. This finding agrees with that of previous studies on the effects of thermal cycling on wear (Mair; 1991; Chadwick, 1994). The wear resistance of both Silux and Z100 was not affected by thermal cycling. Mair (1991) also reported that the wear resistance of Silux was not affected by thermal cycling. At all wear intervals (2,000 to 10,000 cycles), increased wear was observed with Ariston specimens cycled at an upper temperature limit of 60ºC. From 4,000 cycles onwards, wear of specimens in this treatment group was also significantly higher than specimens cycled at an upper temperature 45ºC. No significant difference in wear was observed between the control group and specimens cycled at an upper temperature of 45ºC. As a cup temperature of 55ºC produced the maximum comfortable tooth surface temperature of 47ºC (Plant & others, 1974), and tooth surface temperature during a hot food meal was reported to be between 43ºC and 53ºC (Crabtree & Atkinson, 1955), the effects of thermal cycling on Ariston may not be significant for most patients. The early wear resistance of Surefil appeared to be significantly decreased by thermal cycling. Surefil specimens cycled at both 45ºC and 60ºC had significantly more wear than the water-stored control specimens after 2,000 cycles of wear testing. At 4,000 cycles, only specimens cycled at the upper temperature of 60ºC had significantly more wear than the control. In addition to surface microcracking, thermal cycling may also increase depth and rate of diffusion of water (Mair, 1989). Based on the wear data, the affected layer is estimated to be less than 20 µm for Surefil. No significant difference in wear was observed between the thermal cycled and control groups after 6,000 cycles of wear testing. This finding can partly account for the low wear observed with Surefil upon removal of the surface layers.

As the filler volume and size were different for both Silux and Z100, these parameters cannot be used to explain the different effects of thermal cycling on composite wear. From the technical profiles of the composites in Table 1, two significant differences in formulation between the composites affected by thermal cycling and those not affected thermocycling were obvious. They were the polymer and filler types. Composites affected by thermal cycling (Ariston and Surefil) contained urethane either as a dimethacrylate or urethane-modified BisGMA. Both urethane dimethacrylate (UDMA) and urethane-modified BisGMA may have greater surface dimensional changes when subjected to thermal stresses compared to BisGMA. In addition, both composites employed the use of fluorosilicate glass for improved fluoride release. The relative contribution of these parameters to the effects of thermal cycling on wear cannot be verified in this study and warrants further investigation. Ariston pHc (pH controlled) is the first "smart" dental composite to be developed and marketed. The material uses a low oral pH to increase fluoride release, and this episodic release prolongs the therapeutic usefulness of the composite and optimizes fluoride release (Combe & Douglas, 1998). For more effective fluoride and ionic release, the composite structure needs to be more open (Combe

& Douglas, 1998); this may make Ariston more susceptible to hydrolysis and the effects of thermal stresses. After 2,000 cycles of wear testing, the wear of thermal cycled Ariston specimens was 1.4 to 2.1 times greater than water-stored controls. Thermal cycled Surefil specimens had 1.3 to 1.5 times more wear than control specimens. The upper temperature limit of 60ºC resulted in greater wear in both composites.

After 10,000 cycles of wear testing, significant differences in wear between materials appeared to be similar for all treatment groups. Z100 had significantly more wear than Silux, Ariston and Surefil. Although no significant differences in wear was observed among the latter three composites for treatment Groups 1 and 2, Ariston had significantly more wear than Silux and Surefil after thermal cycling at an upper temperature of 60ºC. The results can be partially explained by the effects of thermal cycling and the composition/ microstructure of the composites. The latter, together with the correlation of counterbody loss to composite wear, had been studied in depth in another study (Yap & others, 2000).

## CONCLUSIONS

Under the conditions of this *in vitro* study:

1. the effect of thermal cycling on wear was material dependent;

2. the wear of Silux and Z100 were not significantly affected by thermal cycling;

3. thermal cycling of Ariston at an upper temperature of 60ºC significantly decreased wear resistance;

4. thermal cycling at upper temperatures of 45/60ºC decreased early wear resistance of Surefil and

5. for all treatment groups, Z100 had significantly more wear than Silux, Ariston and Surefil.

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# Marginal Quality of Tooth-Colored Restorations in Class II Cavities After Artificial Aging

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K-H Kunzelmann • R Hickel

### Clinical Relevance

Marginal quality of tooth-colored restorations in large Class II cavities achieves satisfactory results to enamel-limited margins but adhesion to dentin is still challenging.


## SUMMARY

**This** in vitro **study compared the proximal marginal adaptation of direct composite restorations with composite and ceramic inlays inserted with different resin cements. Standardized MOD Class II inlay cavities with one proximal box extending below and the other above the CEJ were cut in 48 extracted human molars and randomly assigned to six groups (n=8). Incrementally layered direct composite restorations (P60), composite inlays (P60) and ceramic inlays (Empress; Cerec Vitablocs Mark II) were placed in the cavities. Three different resin cements (RelyX ARC; Variolink II high viscosity; Panavia 21) were used for luting the composite inlays. All ceramic inlays were cemented with RelyX ARC. After finishing and polishing, the teeth were stored for 24 hours in Ringer solution at 37°C before they were subjected to thermal and mechanical loading (5/55°C, 2000x; 50 N vertical load, 50000x). Margins were evaluated on epoxy replicas using a scanning electron microscope at X200 magnification. Statistical analysis was performed with non-parametric test methods (a=0.05). The adhesive interfaces to enamel exhibited high percentages of perfect margins for all groups (91.8% to 96%) and a maximum of 5.2% marginal gap formation. Dentin-limited cavity segments demonstrated more marginal openings and less perfect margins than enamel-bound areas; however, this was only statistically significant for direct composite restorations and composite inlays inserted with Variolink II and Panavia 21. RelyX ARC showed a significantly better adaptation to P60 inlays compared with the leucite-reinforced Empress ceramic but not the Vitablocs Mark II ceramic.**


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## INTRODUCTION

Tooth-colored restorations in posterior teeth are an integral and crucial element of state-of-the-art dentistry (Manhart & others, 1999a; Scheibenbogen & others, 1998). Many different new materials for esthetic dentistry were recently introduced by the dental manufacturers, including compomers, flowable and packable composites, ormocers, improved resin cements and ceramics (Hickel, 1997; Hickel & others, 1998; Krämer & others, 1999; Manhart & others, 1999b, Manhart & others, 2000). The longevity of direct and indirect composite restorations and ceramic inlays is determined, among other factors, by the quality of the marginal adaptation. The marginal fit and adaptation of tooth-colored inlays are reported to be crucial parameters for clinical success (Gladys & others, 1995; Scheibenbogen & others, 1998). Factors which influence the marginal quality are polymerization shrinkage, bond strength, wetting properties, cavity geometry, the C-factor, operative technique and difficulties in access for dental treatment in the posterior region (Feilzer, de Gee & Davidson, 1987; Friedl & others, 1997; Lutz, Krejci & Barbakow, 1991; Scheibenbogen & others, 1998). The placement of direct composite restorations in posterior teeth is accompanied by several problems, such as polymerization shrinkage, residual internal stresses, microleakage and wear. Different strategies, which partly have a synergistic effect, are being employed by clinicians to alleviate the negative effects of polymerization shrinkage on the marginal adaptation of direct tooth-colored restorations. An incremental placement technique, the use of prefabricated inserts and sophisticated light curing concepts, such as softstart-polymerization and direction of the shrinkage vectors, result in better marginal quality and less microleakage (Bott & Hannig, 1995; Dietschi & others, 1995; Krejci, Sparr & Lutz, 1987; Mehl, Hickel & Kunzelmann, 1997). Indirect composite inlays avoid some of the shortcomings of direct restorations. Their physical and mechanical properties are enhanced and residual internal stresses relieved by post-curing the body of the restoration. The negative effects of polymerization shrinkage are limited to the width of the luting gap (Gladys & others, 1995). In addition, laboratory and chairside-fabricated ceramic restorations possess a high degree of biocompatibility, a better coefficient of thermal expansion compared with composite restorations, a more uniform stress transfer across the adhesive interface and better and more durable esthetic properties (Baumann & Heidemann, 1991; Gladys & others, 1995; Manhart & others, 1996; van Dijken & Horstedt, 1994).

Despite improvements in the formulation of modern dentin adhesive systems, the bond strength and marginal adaptation of composite resins to dentin is still inferior and less predictable than adhesion to enamel (Dietrich & others, 1999; Manhart & others, 1999b). However, in clinical dentistry most of the cavities, especially when restorations in the posterior region of the mouth are replaced, are not limited exclusively within enamel but show a mixed type configuration with finishing lines in enamel as well as in dentin (Dietrich & others, 1999; Mayer, 1991). In particular, the adhesive interface between tooth and restorative material at the gingival finish line has been recognized as one of the most problematic regions (Dietschi & others, 1995; Lutz & Kull, 1980). The use of composite and ceramic inlay techniques has proved to be an effective way to improve the marginal seal and adaptation on both enamel and dentin margins by greatly restricting the volume of the composite to be bonded and cured intraorally to a relatively thin film (Dietschi & others, 1995; Krejci, Picco & Lutz, 1990a; Shortall & others, 1989; van Dijken & Horstedt, 1994). The long-term clinical success of adhesive inlays is dependent on a number of factors, of which the luting resin is one of significant interest (van Dijken & Horstedt, 1994).

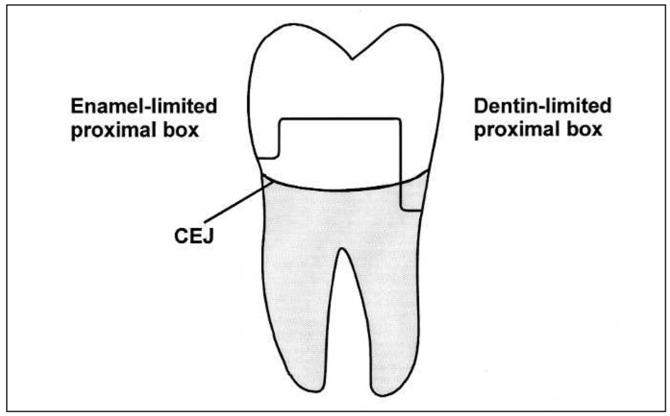


Figure 1. *Illustration of the standardized Class II inlay cavities (CEJ = cemento-enamel junction).*

This *in vitro* investigation determined the marginal quality of artificially aged direct composite and indirect adhesive inlay restorations cemented with different resin cements in large MOD Class II cavities by means of a replica technique at different locations using a scanning electron microscope.

## METHODS AND MATERIALS

### Specimen Preparation

Forty-eight freshly extracted caries-free human molars of the permanent dentition, stored in a 0.25% mixture of sodium azide in Ringer solution until the date of use, were used in this *in vitro* study. After cleaning the teeth with scalers and polishing with pumice, standardized Class II inlay cavities (MOD) were prepared with one proximal box limited within enamel (1-1.5 mm above the cemento-enamel junction) and one proximal box extending into dentin (1-1.5 mm below the cemento-enamel junction) (Figure 1). The dimensions of the cavities were 4.0 mm in width and 3-3.5 mm in depth at the occlusal isthmus and 5.0 mm in width at the proximal boxes. The depth of the proximal boxes in direction to the axial pulpal walls was 1.5 mm. To achieve diver-

Table 1. *Experimental Groups and Products Used (N/A = Not Applicable*

| Group | Restoration Type | Restorative Material | Resin Cement | Bonding Agent |
|---|---|---|---|---|
| DCOR | Direct composite restoration | Filtek P60 (3M Dental Products, St Paul, MN 55144) Batch #30998 | N/A | Single Bond (3M Dental Products, St Paul, MN 55144) Batch #8BR |
| COIR | Indirect composite inlay | Filtek P60 (3M Dental Products, St Paul, MN 55144) Batch #30998 | RelyX ARC (3M Dental Products, St Paul, MN 55144) Batch #19981217 | Single Bond (3M Dental Products, St Paul, MN 55144) Batch #8BR |
| COIV | Indirect composite inlay | Filtek P60 (3M Dental Products, St Paul, MN 55144) Batch #30998 | Variolink II high viscosity (Vivadent, Schaan, Liechtenstein) Batch #A19100 | Syntac Classic (Vivadent,Schaan, Liechtenstein) Batch #A21648 |
| COIP | Indirect composite inlay | Filtek P60 (3M Dental Products, St Paul, MN 55144) Batch #30998 | Panavia 21 (Kuraray Corp, Osaka, Japan) Batch #41119 | ED Primer (Kuraray Corp, Osaka, Japan) Batch #41119 |
| CEIE | Indirect ceramic inlay | IPS Empress (Vivadent, Schaan, Liechtenstein) Batch #A22239 | RelyX ARC (3M Dental Products, St Paul, MN 55144) Batch #19981217 | Single Bond (3M Dental Products, St Paul, MN 55144) Batch #8BR |
| CEIC | Direct CAD/CAM Cerec ceramic inlay | Cerec 2 Vitablocs Mark II (Vita Zahnfabrik, Bad Säckingen, Germany) Batch #5637S | RelyX ARC (3M Dental Products, St Paul, MN 55144) Batch #19981217 | Single Bond (3M Dental Products, St Paul, MN 55144) Batch #8BR |

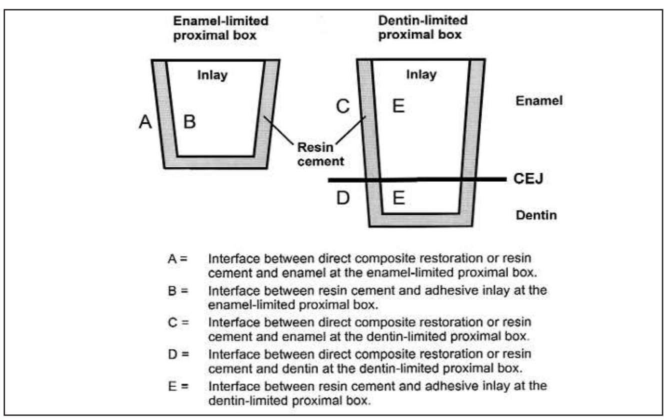


Figure 2. *Illustration of the differentiation among the different marginal interfaces (CEJ = cemento-enamel junction).*

gence angles between opposing walls of 10 to 12 degrees, cavities were prepared using coarse diamond burs with a slight taper (855.314, Komet, Lemgo, Germany) in a high-speed dental handpiece with copious water spray. Fine-grained diamond burs of the same shape (8855.314, Komet, Lemgo, Germany) were used for finishing the preparations. The internal point and line angles were rounded and the enamel margins were not beveled but prepared in butt-joint configuration (Manhart & others, 1999b). After visual inspection of the cavities for imperfect finish lines, the 48 prepared teeth were randomly assigned to six experimental groups with eight teeth each (Table 1), corresponding to the different restorative techniques. Manufacturers' instructions for each material were strictly followed.

For the direct composite restorations (DCOR), the cavities were encircled with a metal matrix band prior to conditioning all enamel and dentin surfaces of the cavities with 35% phosphoric acid gel (Scotchbond Etchant, 3M Dental Products, St Paul, MN 55144) for 15 to 20 seconds (total etch technique). After thoroughly rinsing with water, the cavities were then dried with oil-free compressed air, taking care to avoid desication of the tooth substrate (moist bonding technique). Following the application and light curing of the adhesive system (Single Bond, 3M Dental Products, St Paul, MN 55144), the cavities were restored using a horizontal layering technique with five increments of composite (Filtek P60, 3M Dental Products, St Paul, MN 55144) at the dentin-limited proximal box and three increments at the enamel-limited box. Each increment was light cured individually for 20 seconds from the occlusal direction with a visible light curing unit (Elipar Highlight, standard mode, ESPE, Seefeld, Germany). The light output of the curing unit was monitored throughout the study with a light meter (Curing Radiometer Model 100, Demetron Research Corp, Danbury, CT 06810) and determined 800 $mW/cm^2$. After removal of the metal matrix band, the occlusal portion of the restorations was built up in three increments, cured occlusally and through the remaining cavity

Table 2. *Criteria for Assessment of Marginal Quality of Adhesive Restorations*

| Criterion | Description |
|---|---|
| Perfect margin | The interface between the restorative material and tooth structure (or inlay) exhibits a smooth surface without any interruption in continuity. |
| Marginal opening | The interface between the restorative material and tooth structure (or inlay) is separated by a gap caused by an adhesive failure. |
| Marginal swelling | The interface between the restorative material and tooth structure (or inlay) exhibits a swelling phenomenon at the cavity margin. |
| Artifact | The interface between the restorative material and tooth structure (or inlay) cannot be exactly assessed, that is, due to overhanging excess material or errors in the replication procedure (voids). |

Table 3. *Marginal quality of the interface between direct composite restoration or resin cement and enamel at the enamel-limited proximal box as mean percentage (standard deviation) of the entire length of the particular margin.*

| Experimental Group | Marginal Quality | | |
|---|---|---|---|
| | Perfect Margin | Marginal Opening | Marginal Swelling |
| ***H-test*** | *p*=0.32 | *p*=0.01 | *p*=0.52 |
| **DCOR** | 95.0 (3.9)[a] | 2.9 (2.9)[a,b] | 0.0 (0.0)[a] |
| **COIR** | 96.0 (2.3)[a] | 1.1 (1.7)[a] | 0.1 (0.4)[a] |
| **COIV** | 94.5 (4.1)[a] | 0.8 (1.5)[a] | 0.0 (0.0)[a] |
| **COIP** | 91.8 (4.4)[a] | 5.2 (2.0)[b] | 0.0 (0.0)[a] |
| **CEIE** | 94.3 (3.0)[a] | 0.8 (1.1)[a] | 0.0 (0.0)[a] |
| **CEIC** | 92.6 (4.3)[a] | 2.2 (4.3)[a,b] | 0.0 (0.0)[a] |

Superscripts indicate statistically homogeneous subsets within each criterion for marginal quality among the different experimental groups.

Table 4. *Marginal quality of the interface between resin cement and adhesive inlay at the enamel-limited proximal box as mean percentage (standard deviation) of the entire length of the particular margin (N/A = not applicable).*

| Experimental Group | Marginal Quality | | |
|---|---|---|---|
| | Perfect Margin | Marginal Opening | Marginal Swelling |
| *H-test* | *p=0.01* | *p=0.01* | *p=1.00* |
| **DCOR** | N/A | N/A | N/A |
| **COIR** | 97.5 (1.4)[b] | 0.1 (0.3)[a] | 0.0 (0.0)[a] |
| **COIV** | 95.7 (4.0)[b] | 0.0 (0.0)[a] | 0.0 (0.0)[a] |
| **COIP** | 96.0 (3.1)[b] | 1.3 (1.7)[a] | 0.0 (0.0)[a] |
| **CEIE** | 90.5 (2.3)[a] | 5.0 (3.6)[b] | 0.0 (0.0)[a] |
| **CEIC** | 95.0 (3.9)[a,b] | 1.7 (3.5)[a,b] | 0.0 (0.0)[a] |

Superscripts indicate statistically homogeneous subsets within each criterion for marginal quality among the different experimental groups.

Table 5. *Marginal quality of the interface between direct composite restoration or resin cement and enamel at the dentin-limited proximal box as mean percentage (standard deviation) of the entire length of the particular margin.*

| Experimental Group | Marginal Quality | | |
|---|---|---|---|
| | Perfect Margin | Marginal Opening | Marginal Swelling |
| ***H-test*** | *p=0.99* | *p=0.98* | *p=1.00* |
| **DCOR** | 93.3 (5.0)[a] | 2.6 (3.8)[a] | 0.0 (0.0)[a] |
| **COIR** | 93.7 (2.8)[a] | 2.3 (2.5)[a] | 0.0 (0.0)[a] |
| **COIV** | 94.4 (5.0)[a] | 3.2 (5.2)[a] | 0.0 (0.0)[a] |
| **COIP** | 93.7 (6.5)[a] | 3.1 (4.4)[a] | 0.0 (0.0)[a] |
| **CEIE** | 94.2 (5.4)[a] | 1.5 (2.3)[a] | 0.0 (0.0)[a] |
| **CEIC** | 93.0 (5.1)[a] | 2.4 (3.5)[a] | 0.0 (0.0)[a] |

Superscripts indicate statistically homogeneous subsets within each criterion for marginal quality among the different experimental groups.

walls for 20 seconds each.

For the composite inlay specimens, impressions of the cavities were made with a polyether material (Impregum F, ESPE). Provisional restorations were made with a temporary light-cured resin material (Fermit-N, Vivadent, Batch #B12254) and the teeth were stored in Ringer solution until insertion of the inlays. Composite inlays (Filtek P60, 3M Dental Products, St Paul, MN 55144) were made in the laboratory on isolated master dies of dental stone (Fujirock, GC Corp, Tokyo, Japan), analogous to the procedure described for the direct composite restorations but without placing a matrix band. After finishing, the composite inlays were removed from the die and post-cured in a light oven (Dentacolor XS, Heraeus Kulzer, Wehrheim, Germany) for 180 seconds to enhance the degree of cure and to improve the physical properties. The internal adhesive surfaces of the composite inlays were etched for 15 seconds with 5% hydroflu-

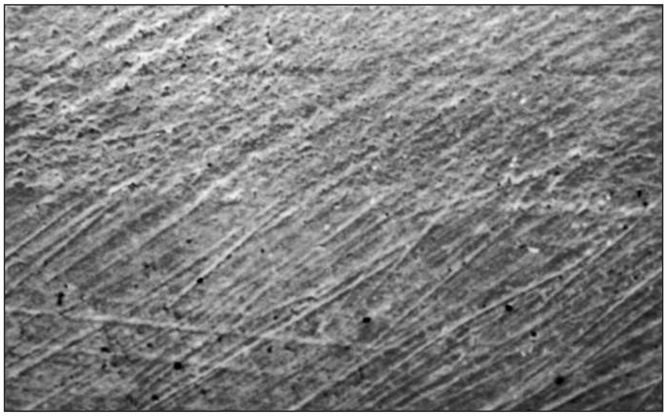

Figure 3. *Perfect margin. The interface between the restorative material and tooth demonstrates a smooth surface without any interruption (magnification 200x).*

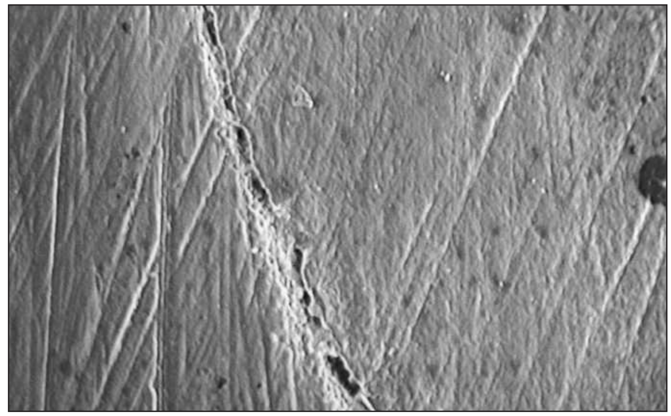

Figure 4. *Marginal opening. The interface between the restorative material and tooth exhibits a gap (magnification 200x).*

Figure 5. *Marginal swelling. The interface between the restorative material and tooth exhibits a swelling phenomenon at the cavity margin (magnification 200x).*

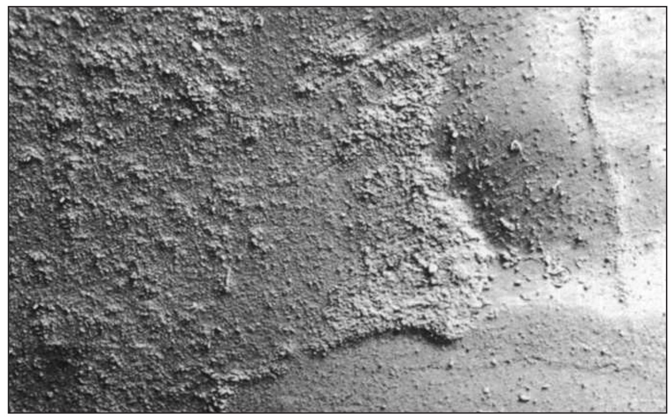

Figure 6. *Artifact. The adhesive interface cannot be assessed because of overhanging excess material at the dentino-enamel junction (magnification 100x).*

oric acid gel (Vita Ceramics Etch, Vita, Bad Säckingen, Germany), then thoroughly rinsed and dried, before application of a silane coupling agent (ESPE-Sil, ESPE). Before adhesive cementation, the teeth of the three composite inlay groups were conditioned and primed corresponding to the instructions of the three manufacturers of the different resin cements/dentin adhesive systems. The inlays were inserted with three different resin cements (RelyX ARC, 3M Dental Products, St Paul, MN 55144; Variolink II high viscosity, Vivadent; Panavia 21, Kuraray Corp) using the ultrasonic insertion technique (USI), which allows the use of highly viscous luting composites for cementation of adhesive inlays by taking advantage of their thixotropic properties by a temporary decrease in viscosity when ultrasonically activated (Scheibenbogen & others, 1997; Scheibenbogen & others, 1998). The luting gaps of the inlays cemented with Panavia 21 (chemically activated) were covered with Oxyguard (Kuraray Corp). The other inlays were covered with Airblock (Dentsply, Konstanz, Germany) prior to light activation of the luting resin to avoid an oxygen-inhibited superficial layer of resin cement. Each restoration surface of the groups COIR and COIV was light cured for 60 seconds (Elipar Highlight, standard mode, ESPE).

After taking impressions, an experienced dental technician made the Empress inlays (Vivadent) in the laboratory. The Cerec inlays (Cerec 2, Sirona, Bensheim, Germany; Vitablocs Mark II ceramic, Vita Zahnfabrik) were made after optical impression of the natural prepared teeth. All composite and Empress inlays were definitely inserted within one week after the impression was made. The Cerec inlays were cemented immediately after optical impression and milling. The internal surfaces of the ceramic inlays were etched for 60 seconds with 5% hydrofluoric acid gel (Vita Ceramics Etch, Vita, Bad Säckingen, Germany) and thoroughly rinsed and dried before application of a silane coupling agent (ESPE-Sil, ESPE). All ceramic inlays were inserted as described above on the conditioned and primed teeth (Single Bond, 3M Dental Group) using the resin cement RelyX ARC (3M Dental Group).

Table 6 *Marginal quality of the interface between direct composite restoration or resin cement and dentin at the dentin-limited proximal box as mean percentage (standard deviation) of the entire length of the particular margin.*

| Experimental Group | Marginal Quality | | |
|---|---|---|---|
| | Perfect Margin | Marginal Opening | Marginal Swelling |
| ***H-test*** | ***p=0.01*** | ***p=0.02*** | ***p=0.01*** |
| **DCOR** | 72.9 (7.4)[a,b] | 18.0 (7.1)[a,b] | 7.9 (4.7)[a,b,c] |
| **COIR** | 88.2 (18.6)[b] | 6.0 (11.8)[a] | 1.5 (3.1)[a] |
| **COIV** | 63.4 (18.3)[a] | 20.3 (9.7)[b] | 11.9 (9.2)[b,c] |
| **COIP** | 64.1 (10.6)[a] | 17.7 (7.1)[a,b] | 15.0 (5.1)[c] |
| **CEIE** | 85.8 (8.5)[a,b] | 8.9 (7.3)[a,b] | 0.0 (0.0)[a] |
| **CEIC** | 81.8 (15.4)[a,b] | 9.7 (7.3)[a,b] | 3.2 (5.7)[a,b] |

Superscripts indicate statistically homogeneous subsets within each criterion for marginal quality among the different experimental groups.

Table 7. *Marginal quality of the interface between resin cement and adhesive inlay at the dentin-limited proximal box as mean percentage (standard deviation) of the entire length of the particular margin (N/A = Not applicable).*

| Experimental Group | Marginal Quality | | |
|---|---|---|---|
| | Perfect Margin | Marginal Opening | Marginal Swelling |
| ***H-test*** | ***p=0.04*** | ***p=0.04*** | ***p=1.00*** |
| **DCOR** | N/A | N/A | N/A |
| **COIR** | 96.0 (4.2)[b] | 0.9 (1.8)[a] | 0.0 (0.0)[a] |
| **COIV** | 91.4 (5.2)[a,b] | 3.8 (3.6)[a,b] | 0.0 (0.0)[a] |
| **COIP** | 93.3 (3.9)[a,b] | 3.1 (2.9)[a,b] | 0.0 (0.0)[a] |
| **CEIE** | 86.2 (7.8)[a] | 9.1 (7.4)[b] | 0.0 (0.0)[a] |
| **CEIC** | 91.4 (8.5)[a,b] | 3.7 (5.1)[a,b] | 0.0 (0.0)[a] |

Superscripts indicate statistically homogeneous subsets within each criterion for marginal quality among the different experimental groups.

All restorations were finished and polished immediately after placement using finishing diamond burs and polishing disks (Sof-Lex, 3M Dental Products, St Paul, MN 55144).

### Thermocycling and Mechanical Loading

After 24 hours storage in distilled water at 37°C, the restored teeth were subjected to artificial aging by thermocycling and mechanical loading. All specimens were alternately immersed in water baths at 5°C and 55°C for 2,000 cycles, with a dwell time of 30 seconds in each bath and a transfer time of 15 seconds. Mechanical loading of the teeth, mounted on metallic specimen holders with a light curing composite, was conducted in the Munich Oral Environment (Kunzelmann, 1998; Manhart, Kunzelmann & Hickel, 1996). The carefully aligned teeth were loaded in the central fossa of the restorations in axial direction with a force of 50 N for 50,000 times at a 1 Hz frequency. The antagonist material was a Steatit sphere with 5 mm diameter, which exhibits a hardness and wear resistance similar to natural enamel (Kunzelmann, 1998; Wassell, McCabe & Walls, 1992; Wassell, McCabe & Walls, 1994a; Wassell, McCabe & Walls, 1994b). The metal specimen holders were mounted on a hard rubber element that allowed a sliding movement of the tooth between the first contact on an inclined plane to the central fossa (Dietschi & Herzfeld, 1998). During mechanical loading, the teeth were continuously immersed in Ringer solution. This oral simulation device exhibits similar function to the machine developed by Krejci & others (1990b).

### Specimen Evaluation

After thermal and mechanical loading, impressions of the restored teeth were taken using a polyether material (Impregum F, ESPE). Replicas were made by casting the impressions with an epoxy resin and gold sputtered (SEM Autocoating Unit E5200, Polaron Equipment Ltd, Watford, England). The interface between composite and tooth tissues for direct composite restorations and between luting cement and tooth tissues for adhesive inlays at the proximal extensions was analyzed with an established quantitative and qualitative marginal analysis (Dietrich & others, 1999; Dietschi & Herzfeld, 1998; Friedl & others, 1997) in a scanning electron microscope (Leitz AMR1200, Leitz, Wetzlar, Germany) at 200x magnification. For adhesive inlays, the interface between the resin cement and the inlay was evaluated as well. Differentiations between enamel-limited and dentin-limited interfaces were made (Figure 2). The SEM evaluation was performed by a single qualified operator using the criteria listed in Table 2 and depicted in Figures 3 to 6. Results of the marginal quality, based on the four rating categories, are expressed as the percentage of the total length of the particular margin that fell into each category.

### Statistical Analysis

Mean values and standard deviations of eight replications were calculated for each assessed marginal interface. Preliminary analysis of the data (SPSS for Windows, Version 8.0, SPSS Inc, Chicago, Ill 60611) did not show normal distribution for all experimental groups (Shapiro-Wilks test) and homogeneity of variances (Levene's test). Further statistical analysis among the experimental groups for each assessed marginal interface was performed with non-parametric test methods, using the Kruskal-Wallis H-test and Mann-Whitney U-tests with Bonferroni correction for pairwise multiple comparisons at a significance level of $p<0.05$. Performance differences for enamel margins (Interface A; Figure 2) and dentin margins (Interface D; Figure 2) within each experimental group were statistically analyzed using the Mann-Whitney U-test at a significance level of $p<0.05$.

## RESULTS

Marginal areas assessed with the criterion "artifact" are a result of overhanging excess material or errors during the replication procedure. No assessed margin exhibited more than 5% artifact segments, these results are therefore not reported. Mean percentages, standard deviations and statistical significances of "perfect margins," "marginal opening" and "marginal swelling" differentiated by enamel-limited, dentin-limited and luting cement-inlay interfaces are reported in Tables 3 to 7.

### Interface Between Restoration and Enamel at the Enamel-Limited Proximal Box (Table 3)

The proximal adaptation of the restorations to enamel at the enamel-limited extension exhibited high percentages of perfect margin after artificial aging, ranging from 91.8% to 96.0% without significant differences among the groups. Composite inlays inserted with Panavia 21 (COIP) demonstrated significantly more marginal gap formation (5.2%) than composite inlays inserted with RelyX ARC (COIR, 1.1%) and Variolink II (COIV, 0.8%), respectively, and Empress ceramic inlays (CEIE, 0.8%).

### Interface Between Resin Cement and Adhesive Inlay at the Enamel-Limited Proximal Box (Table 4)

The composite inlays showed a significantly better marginal adaptation to the three different resin cements than Empress ceramic inlays (90.5% perfect margins and 5% gap formation) with respect to perfect margins (95.7% to 97.5%) as well as marginal openings (0% to 1.3%).

### Interface Between Restoration and Enamel at the Dentin-Limited Proximal Box (Table 5)

Marginal quality of all experimental groups to enamel at the dentin-limited proximal extension showed comparable results to the findings at the enamel-limited box. High percentages of perfect margins were recorded in a narrow range from 93.0% to 94.4%. Marginal gap formation could be detected from 1.5% to 3.2%. No significant differences were found among the different groups.

### Interface Between Restoration and Dentin at the Dentin-Limited Proximal Box (Table 6)

Composite inlays inserted with RelyX ARC (COIR) exhibited significantly more perfect margins (88.2%) than composite inlays luted with Variolink II (COIV, 63.4%) and Panavia 21 (COIP, 64.1%) and less marginal gap formation (6%) compared with Variolink II (20.3%). Marginal swelling could be detected only at the interface between dentin and restorative materials. Panavia 21 (15%) and Variolink II (11.9%) and their corresponding bonding systems showed considerable amounts of marginal swelling, a significantly higher percentage than RelyX ARC and Single Bond (maximum 3.2%). Direct composite restorations (DCOR) and both ceramic inlay systems showed no significant differences with respect to their marginal adaptation to dentin.

### Interface Between Resin Cement and Adhesive Inlay at the Dentin-Limited Proximal Box (Table 7)

Marginal quality of all groups between luting resins and composite and ceramic inlays at the dentin-limited proximal box showed similar results compared with the interfaces at the enamel-limited box. Empress ceramic inlays (CEIE) showed less perfect marginal adaptation (86.2%) and more gap formation (9.1%) to the resin cement RelyX ARC than the composite inlays (COIR).

### Influence of Enamel-Limited and Dentin-Limited Adhesive Interfaces

Comparing adhesion of the restorative materials to dentin (Interface D; Figure 2) and enamel (Interface A; Figure 2) within each experimental group showed for direct composite restorations (DCOR) significantly less perfect margins (72.9% vs 95%), more gap formation (18% vs 2.9%) and more marginal swelling (7.9% vs 0%) at the dentin interface. Composite inlays inserted with RelyX ARC (COIR) demonstrated no significant differences for all quality criteria between dentin and enamel (perfect margins: 88.2% vs 96%; gap formation: 6% vs 1.1%; marginal swelling: 1.5% vs 0.1%), whereas composite inlays luted with Variolink II (COIV; perfect margins: 63.4% vs 94.5%; gap formation: 20.3% vs 0.8%; marginal swelling: 11.9% vs 0%) and Panavia 21 (COIP; perfect margins: 64.1% vs 91.8%; gap formation: 17.7% vs 5.2%; marginal swelling: 15% vs 0%) exhibited significantly less percentage of perfectly adapted margins and more marginal openings and swelling phenomena at the dentin-limited margins compared with enamel-bound interfaces. For the Empress ceramic inlays (CEIE; perfect margins: 85.8% vs 94.3%; gap formation: 8.9% vs 0.8%; marginal swelling: 0% vs 0%) as well as the Cerec restorations (CEIC; perfect margins: 81.8% vs 92.6%; gap formation: 9.7% vs 2.2%; marginal swelling: 3.2% vs 0%), no statistically significant differences between dentin and enamel could be found.

## DISCUSSION

Within the limitations of laboratory studies, quantitative marginal analysis by scanning electron microscopy has proven to be an exact and reliable assessment method for the evaluation of the marginal adaptation of adhesive restorations (Friedl & others, 1997; Gladys & others, 1995; Kunzelmann, Krause & Hickel, 1993; Roulet, 1994). Marginal adaptation of the restorative systems to hard dental tissues and inlay materials was assessed only after artificial aging because no significant information could be obtained from measurements prior to the thermal and mechanical fatigue test in preliminary studies (Dietschi & Herzfeld, 1998).

Marginal quality of all experimental groups to enamel at the enamel, as well as at the dentin-limited proximal box, proved satisfactory with a maximum of 5.2% marginal opening for composite inlays inserted with Panavia 21 (van Dijken & Horstedt, 1994). No significant differences could be detected in the percentage of perfect marginal adaptation among direct composite restorations, composite inlays and ceramic inlays.

In this *in vitro* study, marginal adaptation to dentin was significantly worse compared with enamel-limited sections for direct composite restorations and composite inlays cemented with Variolink II or Panavia 21 (Manhart & others, 1996). Composite inlays and both types of ceramic inlays inserted with RelyX ARC exhibited less percentage of perfect adaptation and more gap formation to dentin as well; however, these differences were statistically significant. Confirming the results of this study, several authors reported that adhesion to dentin for both direct and inlay techniques demonstrated less perfect margins and more marginal openings compared with the enamel-limited cavity segments (Dietrich & others, 1999; Gladys & others, 1995; Schuckar & Geurtsen, 1997; Tyas, 1994). Even with the newest generation bonding systems, which establish considerable high bond strengths to dentin, a perfect bond to dentin without gap formation cannot be established (Friedl & others, 1997). Dentin shows a wider biologic variability than enamel, which makes it much more difficult to create a good adhesion that resists the negative effects of polymerization shrinkage and subsequent thermal and mechanical stress factors. Several studies proved that aging of the resin-dentin interface results in significantly reduced marginal quality and bond strength and more microleakage (Krejci, Guntert & Lutz, 1994; Reich, Schmalz & Federlin, 1990; Schuckar & Geursten, 1997). Marginal swelling could be almost detected only at the interface between restorative materials and dentin (Thonemann & others, 1995). The swelling phenomenon is attributed to water uptake and hygroscopic expansion of the bonding agent (Kunzelmann & others, 1993; Manhart & others, 1999b). ED Primer and Syntac Classic exhibited more percentage in marginal swelling compared with the more recently introduced bonding agent Single Bond. This phenomenon needs to be discussed critically, as it affects the morphology of the adhesive interface and may result in masking existing marginal irregularities and small gaps which can no longer be detected in the SEM (Manhart & others, 1999b, Thonemann & others, 1995). Little is known about the long-term stability and sealing capacity of the swollen marginal areas. It is very likely that under mechanical loading these areas rupture or disintegrate resulting in additional marginal gap formation. Marginal swelling may ultimately lead to restoration problems (Friedl & others, 1997) with increased microleakage and even postoperative symptoms if these swollen areas disintegrate.

The resin cement RelyX ARC showed a significantly better marginal adaptation, with more percentage of perfect margin and less gap formation to the composite inlay compared with the leucite-reinforced Empress ceramic but not the Vitablocs Mark II ceramic. As both types of ceramic inlays were pretreated in exactly the same manner, the different chemical composition of both ceramic systems, in addition to the effect of the Cerec milling wheel, which is likely to result in a more rough surface/marginal edge than the lab-made Empress, may attribute to this difference in marginal behavior. All three types of luting resins established a satisfactory adhesion to the composite inlays as well as to enamel-limited cavity segments. Within the dentin-limited areas, RelyX ARC demonstrated a significantly greater percentage of perfect margins and less marginal gaps than Variolink II and Panavia 21. Concentrating on the experimental groups using Single Bond as bonding agent, the direct composite restorations (DCOR) presented the lowest proportion of continuous margins in dentin compared with the inlay groups (COIR, CEIE, CEIC). These findings are in accordance with those of previous studies reported in the literature that investigated direct and indirect techniques (Dietschi & others, 1995; Krejci & others, 1990a; Shortall & others, 1989). The negative effects of polymerization shrinkage are restricted to the thin film of luting composite when using adhesive inlays, whereas even an incremental layering technique for direct composite restorations results in significantly worse marginal adaptation and increased internal stresses (Dietschi & others, 1995; van Dijken & Horstedt, 1994). However, it has been shown that high stress develops even in thin films of resin composites (Feilzer, de Gee & Davidson, 1989). Furthermore, dimensional changes during thermal and mechanical loading that challenge marginal integrity are less strongly developed for post-cured composite inlays and high modulus ceramic restorations compared with direct composite restorations.

## CONCLUSIONS

The luting resin RelyX ARC provided better marginal adaptation to dentin compared with the other two tested resin cements. Despite improvements in material and application technology, none of the tested restorative systems (direct composite restoration, composite inlay, ceramic inlay) achieved a perfect marginal adaptation, neither in enamel- nor in dentin-bound adhesive interfaces. In general, adhesive interfaces between dentin and restorative systems demonstrated more marginal openings and less-perfect margins than enamel-bound areas.

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# Marginal Fit of Alumina- and Zirconia-Based Fixed Partial Dentures Produced by a CAD/CAM System

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**Clinical Relevance**

The results of this *in vitro* study demonstrate that the Precident DCS system can produce alumina- and zirconia-based all-ceramic fixed partial dentures with an acceptable marginal fit that ensures a favorable clinical prognosis.

## SUMMARY

**Clinical long-term success of all-ceramic dental restorations can be significantly influenced by marginal discrepancies. As a result, this** *in vitro* **study evaluated the marginal fit of alumina- and zirconia-based fixed partial dentures (FPDs) machined by the Precident DCS system. Different master steel models of three-, four- and five-unit posterior FPDs with an 0.8 mm chamfer preparation were produced. FPDs made of DC-Zirkon and In-Ceram Zirconia core ceramics were machined by the Precident DCS system. The marginal fit of the milled frameworks placed on the master steel models was determined by a replica technique using a light-body silicone to fill the discrepancies between crown and tooth and a heavy-body material to stabilize the light-body impression material. The impressions were poured into an epoxy resin material and each model was cross-sectioned with a low speed diamond saw to better visualize marginal discrepancies. The marginal fit of the FPDs was evaluated by scanning electron microscopy. The measurements of the marginal fit exhibited mean marginal discrepancies in a range between 60.5 and 74.0 µm, mean marginal gaps in a range from 42.9 to 46.3 µm, mean vertical discrepancies in a range from 20.9 to 48.0 µm and mean horizontal discrepancies in the range of 42.0 to 58.8 µm. Statistical data analysis was performed using the non-parametric test of Kruskal-Wallis and Mann-Whitney. The analysis revealed no significant differences ($p>0.05$) between the mean marginal gaps and vertical and horizontal discrepancies. However, for some FPDs the mean values of the marginal discrepancies were significantly different ($p \leq 0.05$). The wide range of the measured values may be attributed to the complex geometrical design of long span FPDs and difficulties regarding the milling process of brittle ceramic materials. Based on the selection of 100 µm as the limit of clinical acceptability, the results of this study can conclude that the level of marginal fit for alumina- and zirconia-based FPDs achieved with the Precident DCS system meet the clinical requirements.**

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## INTRODUCTION

Long-term success of all-ceramic crowns and fixed partial dentures (FPDs) largely depends on the accuracy of fit between the restoration and prepared tooth structure. The marginal fit of a ceramic denture to the supporting tooth structure can influence the strength of the restoration (Tuntiprawon & Wilson, 1995) as well as the integrity of the periodontal tissue (Grasso & others, 1985; Bader & others, 1991). Numerous studies have examined the marginal fit of porcelain crowns, whereas only minimal data are available on the accuracy of fixed partial dentures (Campbell & Sozio, 1988; Sorensen & others, 1970). To achieve all-ceramic FPDs with appropriate strength, new alumina- and zirconia-based ceramic materials have recently been introduced (Christel & others, 1989; Seghi & Sorensen, 1995). These materials are manufactured under industrially optimized conditions and are designed to be processed by CAD/CAM (computer-aided design/computer-aided manufacturing) technologies (Luthardt, Rieger & Musil, 1997). The significant advantage in using CAD/CAM technology lies in the fact that room-temperature milling of ceramic materials processed under high-quality processes will yield homogeneous material structures, where voids, flaws and cracks are reduced to a minimum (Tinschert & others, 2000). Therefore, CAD/CAM manufacturing of all-ceramic restorations from an industrially prepared ceramic block can be seen as an alternative technique for fabrication of dental restorations. In addition, this technology also promises highly accurate results. To produce milled restorations with an accurate fit, it is necessary to mechanically or optically scan the prepared tooth surface and convert the data into control signals for computer-assisted milling (Inokoshi & others, 1992; May & others, 1998; Samet & others, 1995). In this regard, CAD/CAM systems have encountered various problems. The shapes of prepared teeth cannot be described by regular geometric methods. Thus, a high-precision data acquisition must be performed to record the complex surface geometry and the correct tooth positions in the dental arch (Willer, Rossbach & Weber, 1998).

This study tested the hypothesis that the marginal fit of alumina- and zirconia-based all-ceramic FPDs produced by the President DCS system achieves the clinically acceptable values required for a favorable clinical prognosis.

## METHODS AND MATERIALS

The upper jaw of a phantom-model (OK-16; KAVO-EWL, Biberach, Germany) was used to clinically create simulated three-, four- and five-unit FPDs (Table 1). Therefore, the right canine, the first and second premolars and the second molar were prepared with chamfer margins for complete crowns. The chamfer preparation of the abutment teeth was performed at first with coarse torpedo diamond burs (Komet, ISO #806 314 28934 012/016; Gebr Brasseler, Lemgo, Germany). The cervical preparation line followed an assumed natural gingival margin contour to simulate clinical conditions. Then, fine diamond burs (Komet, ISO #806 314 289514 012/016) were used to refine the preparation and round all line angles. Finally, the prepared abutment teeth were controlled using a parallelometer (Royal EM Parallelometer; Royal MTG Co, Tokyo, Japan) and a digital slide gauge (Mitutoyo Corporation, Tano-cho, Japan) to ensure standardized tooth preparations with: (1) a total convergence angle of 10 to 12 degrees, (2) circumferential chamfer margins of 0.8 mm and (3) an occlusal reduction of 1.5 mm. Three different working casts were fabricated for each type of FPD, replacing the first molar (three-unit FPD), the second premolar and first molar (four-unit FPD) and both premolars and the first molar (five-unit FPD).

The prepared teeth were placed in their correct positions in the maxillary arch and half-arch impressions of the preparations and adjacent teeth were made with a silicone impression material (President Coltène; Coltène, Altstätten, Switzerland). The impressions were poured in an epoxy resin material (Palavit 55; Kulzer, Wehrheim, Germany) to create a preparation model which was invested, burned out and cast in a nickel-chromium alloy (Wiron 99, Bego; Bremen, Germany). Three different master nickel-chromium models with fixed dies were fabricated for each type of FPD. The surfaces of the dies were finished with rubber polishers,

Table 1: *Materials and Restorations Tested*

| Product Name | Generic Term | Manufacturer | Batch # | Restoration | FDI-Position | Code |
|---|---|---|---|---|---|---|
| DC-Zirkon | Partially stabilized zirconia ceramic | DCS Dental AG, Allschwil, Switzerland | 0000000256 | Three-unit FPD | 15-17 | DZ3 |
| DC-Zirkon | Partially stabilized zirconia ceramic | DCS Dental AG, Allschwil, Switzerland | 0000000256 | Four-unit FPD | 14-17 | DZ4 |
| DC-Zirkon | Partially stabilized zirconia ceramic | DCS Dental AG, Allschwil, Switzerland | 0000000256 | Five-unit FPD | 13-17 | DZ5 |
| In-Ceram Zirconia | Zirconia-reinforced glass-infiltrated | Vita Zahnfabrik, Bad Säckingen, Germany | not available | Three-unit FPD | 15-17 | IZ3 |

first with coarser-grade, then finer-grade rubber cusps and points (Shofu Dental, Ratingen, Germany). The nickel-chromium steel models were used as working casts to fabricate the FPDs and to measure the precision of fit between the crowns and the dies.

All-ceramic FPDs were produced with the Precident DCS system (Digitizing Computer System; Model #M3-115, DCS Dental AG, Allschwil, Switzerland) consisting of a computer station, a mechanical scanning instrument (Digitizer; Model #D3-168-97) and a milling machine (Precimill; Model #M3-115). At first, the tooth preparation and the position of the dies in the dental arch were measured and digitized by the scanning instrument. Then, the data were transmitted to a computer to design and calculate the frameworks of the FPDs. Once the milling paths had been computed, the data were forwarded to the system coordinates of the milling machine. The milling machine, developed for dental applications, was equipped with a high-speed drilling element with interchangeable round diamond burs (DCS Dental AG, Allschwil, Switzerland) of different diameters (1.6, 2.0, 3.0 and 5.0 mm, respectively) and computerized velocity control. Various frameworks were milled from different ceramic blocks manufactured under industrially optimized conditions (Table 1). Three-unit FPDs were produced from group DZ ceramic blocks (95% $ZrO_2$ stabilized by 5% $Y_2O_3$) as well as from group IZ ceramic blanks ($Al_2O_3$ reinforced by 33% $ZrO_2$), whereas four- and five-unit FPDs were produced only from group DZ ceramic. According to the recommendations of the manufacturer, long-span FPDs of group IZ ceramic were excluded from this study. The milling process consisted of three steps: (1) rough inside milling to remove the bulk of the ceramic material, (2) fine inside milling to increase the accuracy of the framework and (3) rough external milling. The frameworks were prepared 1 mm from the actual finish line to prevent inadvertent damage. Therefore, one person did a final manual trimming of the frameworks to remove any excess ceramic material from the crown margin. Additionally, the frameworks of group IZ ceramic were infiltrated with a low viscosity infiltration glass (In-Ceram Zirconia Glass Powder; Vita Zahnfabrik, Bad Säckingen, Germany) according to the manufacturer's instructions.

The marginal fit of the frameworks was measured without veneering porcelain since it can be assumed that the addition of porcelain does not cause any significant changes in marginal integrity (Groten, Girthofer & Pröbster, 1997). Five frameworks of each type of FPD were examined by scanning electron microscopy (SEM). Before measurement, the FPDs were placed on the master nickel-chromium dies without cementation. The fit of the crowns was evaluated by a replica technique using a light-body silicone impression material to fill the discrepancies between crown and tooth and a heavy-body material to stabilize the light-body impression material (President Coltène light body and heavy body; Coltène, Altstätten, Switzerland). Constant finger pressure was applied onto the FPDs while impressions of the marginal crown areas were made. A cast of each FPD was made by pouring epoxy resin (Araldit; Ciba-Geigy, Wehr, Germany). To better visualize marginal discrepancies, each resin model was cut along a cross-sectional plane three times buccolingually and twice mesiodistally with a low-speed saw (Isomet; Wirtz-Buehler, Düsseldorf, Germany) and a diamond saw-blade (15HC 11-4244; Wirtz-Buehler, Düsseldorf, Germany). The sections were then coated with a thin carbon layer using a vacuum evaporator and examined by SEM. A microphotograph of each marginal crown area was recorded at 200x magnification and a photographic print obtained. From these photographic prints, the marginal discrepancies between the crowns and the dies could be measured at different measurement locations according to terminology reported by various authors (Schlegel, Besimo & Donath, 1991; Holmes & others, 1989).

For each type of FPD, measurements were performed to determine the following parameters (Figures 1A-D):

1. Marginal discrepancy: Distance from the internal surface of the crown margin to the preparation finish line (Figure 1A).
2. Marginal gap: Vertical distance from the internal surface of the abutment crown to the prepared tooth surface close to the preparation finish line (Figure 1B).
3. Vertical marginal discrepancy: Distance parallel to the tooth axis from the crown margin to the preparation finish line. Positive or negative values are obtained if the crown margins are respectively too long or too short (Figure 1C).
4. Horizontal marginal discrepancy: Distance perpendicular to the tooth axis from the external surface of the crown margin to the preparation finish line. Positive or negative values are obtained if the crown margins are respectively over- or underextended (Figure 1D).

The same person performed all measurements to minimize variation in the measured values. The mean values and standard deviations of the measured parameters were calculated for each type of FPD. Statistical data analysis was performed at a 0.05 level of significance using Kruskal-Wallis and Mann-Whitney nonparametric tests.

## RESULTS

Table 2 summarizes the mean values and standard deviations of the marginal discrepancies, marginal gaps and vertical and horizontal marginal discrepancies.

Figure 1. *Types of marginal misfit.*

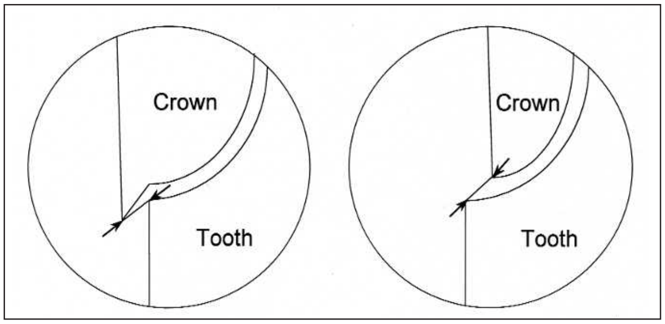


Figure 1A. *Marginal discrepancy.*

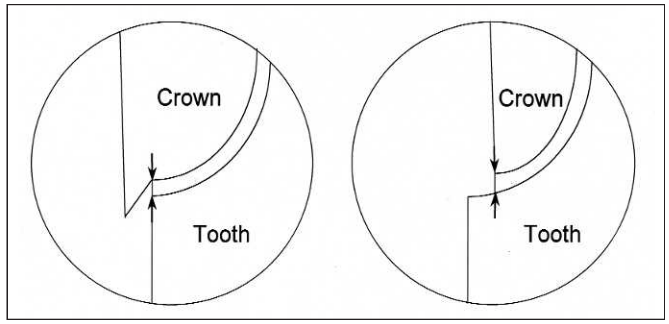


Figure 1B. *Marginal gap.*

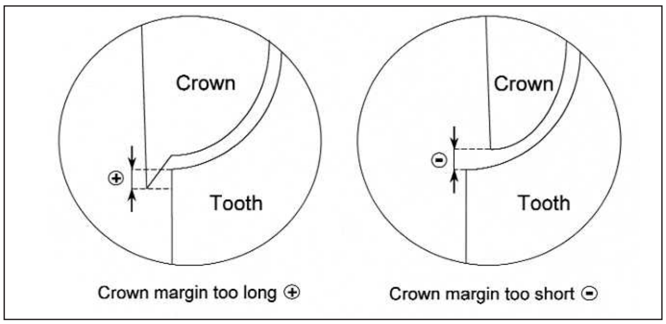


Figure 1C. *Vertical marginal discrepancy.*

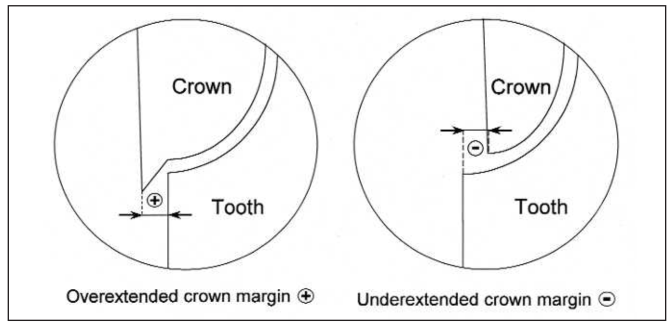


Figure 1D. Horizontal marginal discrepancy.

Table 2: *Mean Values and Standard Deviations in µm of the Measured Marginal Defects*

| Parameter | DZ3 | DZ4 | DZ5 | IZ3 |
|---|---|---|---|---|
| Marginal discrepancy | 66.8 (±33.2) | 71.4 (±26.0)* | 60.5 (±34.7)* | 60.5 (±30.1)* |
| Marginal gap | 44.1 (±13.4) | 46.3 (±19.3) | 46.3 (±19.3) | 45.0 (±19.2) |
| Vertical marginal discrepancy | 20.9 (±57.6) | 47.9 (±45.6) | 47.9 (±48.6) | 48.0 (±40.6) |
| Too long | 64.0 (±42.8) | 69.3 (±45.0) | 65.3 (±9.4) | 46.5 (±17.7) |
| Too short | 46.7 (± 29.7) | 51.8 (±31.8) | 61.2 (±30.0) | 55.0 (±32.1) |
| Horzontal marginal discrepancy | 56.1 (±39.3) | 58.8 (±41.1) | 44.8 (±57.1) | 42.0 (±42.4) |
| Overextended | 60.2 (±34.8) | 63.5 (±36.7) | 65.2 (±31.8) | 51.4 (±26.4) |
| Underextended | 33.0 (±22.6) | 26.7 (±2.5) | 62.0 (±37.0) | 51.4 (±26.4) |

*Mean values of group DZ4 and DZ5 are significantly different ($p \leq 0.05$) compared with the mean value of group IZ3.

Wide distribution of the measured data is graphically represented by box-and-whisker plots (Figures 2A-D) and column charts (Figures 3A-D).

The mean marginal discrepancies ranged from 60.5 to 74.0 µm (Figure 2A). About 90% of the measured crown margins yielded marginal discrepancies below 100 µm (Figure 3A). The mean marginal gaps were in the range between 42.9 and 46.3 µm (Figure 2B). No marginal gap width was observed with a value above 100 µm (Figure 3B). The mean vertical marginal discrepancies ranged from 20.9 to 48.0 µm, whereas the mean horizontal marginal discrepancies ranged from 42.0 to 58.8 µm (Figures 2C,D). The measurements indicated that most of the measured crown margins were either too short (70-93%) or overextended (84-89%) (Figures 3C,D).

The Kruskal-Wallis analysis revealed that the mean values of the marginal gaps and vertical and horizontal marginal discrepancies were not significantly different ($p>0.05$). However, the mean values of the marginal discrepancies were significantly different ($p \leq 0.05$) for some FPDs. With regard to this parameter, the mean values of each of two groups were matched for paired comparison using the Mann-Whitney U-test. This analysis indicated that the mean marginal discrepancies of group DZ4 and DZ5 were significantly different ($p \leq 0.05$) compared with the mean value of group IZ3 (Table 2).

## DISCUSSION

SEM examination generally represents a highly reliable analysis system to determine the marginal fit of dental restorations. In contrast to the results of a light

Figure 2. *Box and Whisker Plots show the median values and the 10th, 25th, 75th and 90th percentile (horizontal lines) of all measurements. Maximum (> 90TH percentile) and minimum (< 10th percentile) values are represented by single points.*

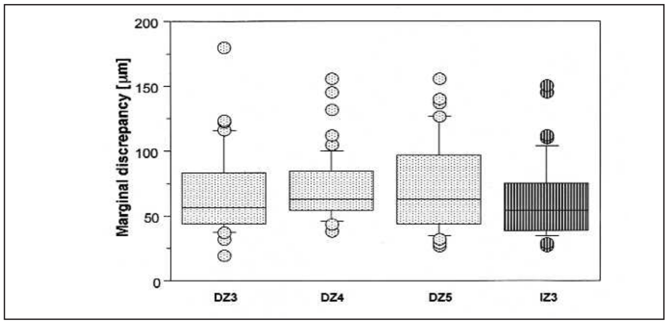


Figure 2A. *Marginal discrepancy.*

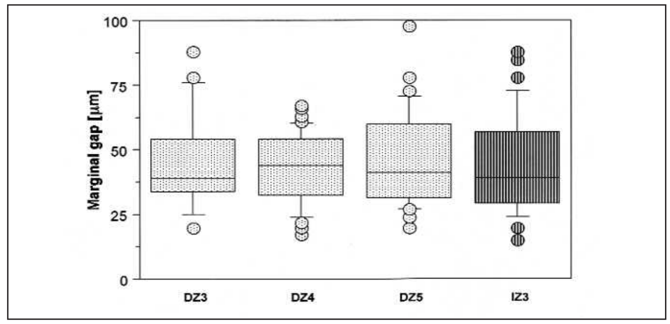


Figure 2B. *Marginal gap.*

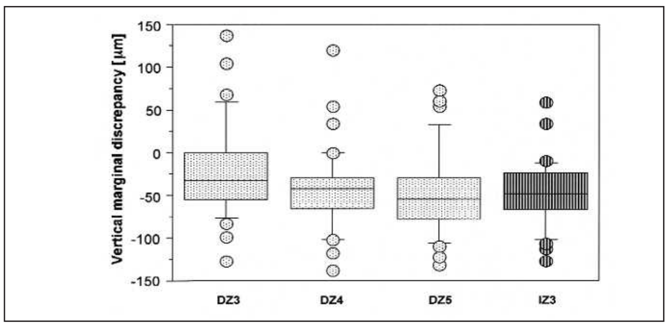


Figure 2C. *Vertical marginal discrepancy.*

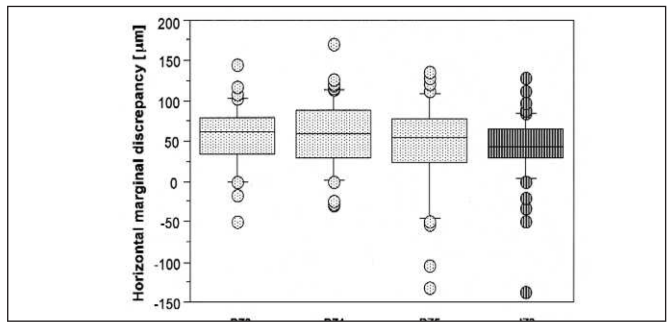


Figure 2D. Horizontal marginal discrepancy.

microscope analysis, SEM data more suitably describe the real marginal configurations (Groten & others, 1997). However, some systematic errors related to the SEM procedures have to be considered. The accuracy in measurement depends on the angle of the surface of the lens, the focus range or working distance and the magnification. The principal errors occur in the angulation and working distance, which are controlled by the technician. Additional variances may result from the manufacture of black and white prints that were used for readings. Therefore, a summarized probability error of about 10% is assumed to occur during the SEM evaluation (Hamaguchi, Cacciatore & Tueller, 1982).

## Marginal Discrepancy

Marginal discrepancies (Figure 1A) have a high clinical relevance because insufficient crown margin lengths predispose the adjacent tooth surfaces to secondary caries and may have an adverse effect on periodontal tissue (Sorensen, Larsen & Dreyer-Jörgensen, 1986). Therefore, location and fit of the cervical crown margins are important to biologic and mechanical restorative failure (Bader & others, 1991). However, the so-called clinically acceptable marginal fit is quite variable in the interpretation of the literature. Previous investigators considered a marginal discrepancy of less than 50 µm might be acceptable; however, it is a value that is seldom clinically achieved (Spiekermann, 1986). McLean and von Fraunhofer (1971) reported discrepancies of less than 80 µm as difficult to detect under clinical conditions. After examining more than 1,000 crowns, they concluded that a marginal discrepancy of ≤ 120 µm is clinically acceptable. Other clinical experience and empirical data, however, suggest that discrepancies of less than 100 µm are appropriate for clinically acceptable crowns (Spiekermann, 1986).

The mean marginal discrepancies of this study ranged between 50 and 100 µm (Table 2), which corresponds to this clinical requirement. However, the wide distribution of the measured data must be considered (Figure 2A and 3A). Although the mean marginal discrepancies were not significantly different for all groups of FPDs, there was a tendency toward higher values with regard to long-span frameworks. Comparing the results of this investigation with different studies on all-ceramic crowns produced by CAD/CAM systems is hardly possible, if not impossible. There are too many differences in restoration designs, preparation procedures and testing methods. However, comparing them with other *in vitro* studies is possible if the Precident DCS system was used. These studies usually evaluated the marginal fit of single crowns made of titanium (Samet & others, 1995; Schlegel & others, 1991) or DC-Zirkon ceramic (Luthardt & others, 1998) after cementation on their respective master dies. Cementing procedures were not used in this investigation because this study evaluated the attainable precision of the Precident DCS system.

Figure 3. *Column charts show the percentage of classified measurements arranged in intervals of 20 µm.*

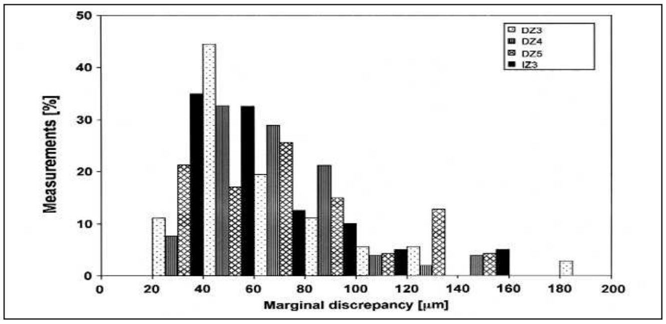


Figure 3A. *Marginal discrepancy.*

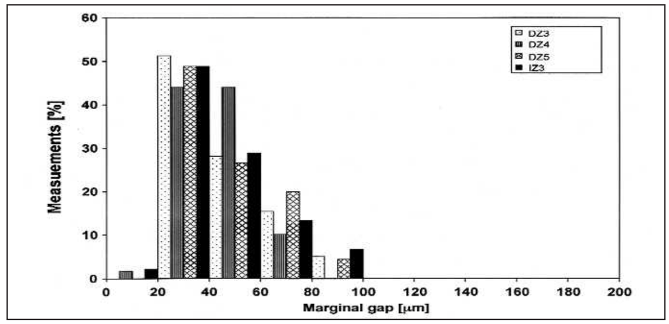


Figure 3B. *Marginal gap.*

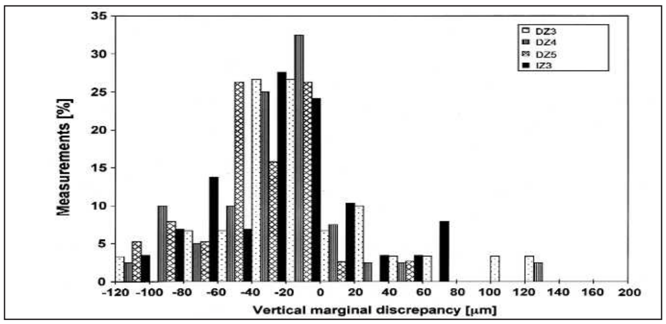


Figure 3C. *Vertical marginal discrepancy.*

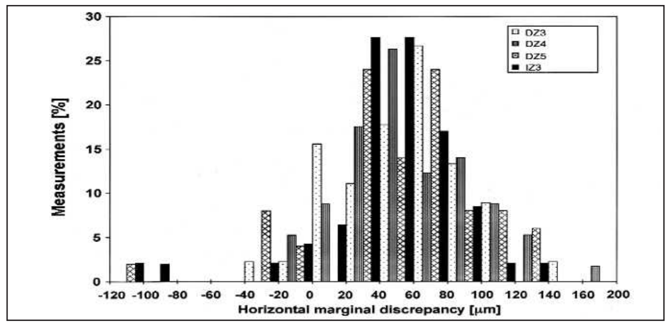


Figure 3D. Horizontal marginal discrepancy.

Cement layers complicate the possibilities of obtaining information about primary precision due to individual manufacturing process (Groten & others, 1997). In addition, cement layers often cover measurement points or at least make them difficult to precisely locate. Unfortunately, only in a few investigations was the marginal fit determined without any cementation layer. These studies were made on either titanium single crowns (Besimo & others, 1995) or three-unit FPDs (Rinke, Hüls & Groth, 1996). The results of these studies conclude that the level of marginal discrepancy achieved with titanium restorations is somewhat more favorable compared with the all-ceramic FPDs this study investigated. Rinke & others (1996) reported that the marginal discrepancies of titanium frameworks for three-unit FPDs produced with the Precident DCS system were in a mean range of 52.0 µm. This is similar to the mean marginal fit of 52.0 µm detected for titanium crowns (Besimo & others, 1995). The difficulties regarding the milling process of brittle ceramic materials, the greater marginal discrepancies and the wide variation of the measured data found in this study may be explained by the complex geometrical design of long-span frameworks. Therefore, further developments of the Precident DCS system should lead to a better adaptation of the manufacturing process to the material properties of alumina- and zirconia-based ceramics.

## Marginal Gap

Despite careful preparation of a full-coverage restoration and its precise cementation, a small gap (Figure 1B) will remain between the margin of the restoration and the finish line of the prepared tooth, predisposing the tooth to caries and periodontal disease (Dreyer-Jorgensen, 1960). The closer the margin of restoration to the finish line of the preparation, the smaller the marginal gap and thickness of exposed cement layer at the margin. For example, it has been shown that the area of exposed cement with a marginal discrepancy of 0.2 mm is three times larger than that of 0.1 mm marginal discrepancy (Silness & Hegdahl, 1970). Poor margins favor cement degradation, which can be described by erosion, mechanical wear and dissolution (Mesu, 1982; Shinkai & others, 1995). It has been reported that cement dissolution is significantly influenced by the preparation design (Dreyer-Jorgensen, 1960) and the type of cement (Ølio, 1991). Most studies conclude that zinc phosphate and glass ionomer show a clinically relevant solubility in oral fluids (Knibbs & Walls, 1989). However, Jacobs and Windeler (1991) found no significant difference in the rate of cement dissolution for marginal gaps in a range between 25 and 75 µm, whereas a gap size of 150 µm demonstrated an increased rate that was statistically significant. Composite luting cements, on the other hand, appear to have properties similar to restorative composites

(Shinkai & others, 1995). They are less soluble than zinc phosphate and glass ionomer cements. However, ethanol and other liquids can soften the composite matrix because of water absorption. Moreover, composites are degraded by enzymes found in human saliva and this hydrolytic activity contributes to the breakdown of composites (Larsen & Munksgaard, 1991). Therefore, it is not known whether the superior behavior of composite cements will continue over a longer period of observation. In this study, the mean marginal gaps ranged from 42.9 to 46.3 µm (Table 2) and no gap width above 100 µm was observed (Figure 2B and 3B). However, an increase in the marginal gap width after cementation must be considered because of the minimal grain size of the dental cement when other faults do not occur (Dreyer-Jorgensen, 1960). Nevertheless, these results seem clinically acceptable for permanent cementation with zinc phosphate and glass ionomer cements commonly used in dentistry.

### Vertical Marginal Discrepancy

Open margin gaps increase microleakage of bacteria and their by-products during dissolution of the luting cement. This can be an important causative factor in pulp inflammation and possible pulp death (Goldmann, Laosonthorn & White, 1992). Moreover, excessive vertical discrepancies (Figure 1C), especially of subgingivally-placed crown margins, tend to harbor periodontal pathogens and impede adequate plaque removal (Felton & others, 1991). Therefore, subgingival margins are consistently associated with more severe gingival inflammation (Bader & others, 1991). Consequences of chronic periodontitis include alveolar bone destruction and possible periodontal breakdown over longer periods (Björn, Björn & Grkovic, 1970). Sorensen & others (1986) reported that the severity of periodontal disease increases with growing subgingival marginal discrepancies. They also suggested that small defects ≤ 50 µm were associated with significantly less fluid flow and bone loss than defects exceeding this value. The mean vertical discrepancies found in this study ranged from 20.9 to 48.0 µm (Table 2). These data indicate that most of the investigated crown margins were too short, with discrepancies less than 50 µm (Figure 2C and 3C). Thus, it can be assumed that these discrepancies are probably acceptable under clinical conditions, even if the defects occur subgingivally.

### Horizontal Marginal Discrepancy

Numerous studies have shown a relationship between horizontal discrepancies of dental restorations (Figure 1D) and periodontal disease (Jeffcoat & Howell, 1980). Grasso & others (1985) reported that the oral health response to crowns apparently relates mainly to inadequate crown contours and embrasures rather than to marginal discrepancies. Underextended margin often results in an emergence profile that is inconsistent with the natural submarginal tooth anatomy, whereas overextended restorations can more negatively affect the periodontal health (Lang, Kiel & Anderhalden, 1983). Generally, it is accepted that overextended margins may contribute to more plaque retention, ginigival inflammation and possible excessive alveolar bone destruction (Björn & others, 1970; Jeffcoat & Howell, 1980). Lang & others (1983) reported that the placement of restorations with overextended subgingival margins resulted in a change in the composition of the subgingival microflora, observed in adult chronic periodontitis associated with increased inflammation and loss of periodontal attachment. Björn & others (1970) reported a highly significant reduction in alveolar bone height for single crown restorations with a marginal excess equal or greater than 200 µm. A lesser, non-significant reduction, however, was related to overextended margins of less than 200 µm. The mean horizontal discrepancies evaluated in this study ranged between 42.0 and 58.8 µm (Table 2). No measurement reached the critical value of 200 µm (Figure 2D and 3D). However, most of the measured crown margins were overextended, probably due to the milling process associated with the Precident DCS system. Therefore, final manual trimming of the crown margins should be controlled under a light microscope to ensure that excess material, which remains after the milling process, is completely removed from the preparation finish line.

## CONCLUSIONS

The findings of this *in vitro* study suggest that the Precident DCS system can produce all-ceramic FPDs with an acceptable marginal fit. It can be concluded from the results of this study that the level of accuracy found for the investigated all-ceramic FPDs meets the clinical requirements. However, because of the tendency for overextended crown margins caused by the milling process of the Precident DCS system, final preparation of the milled frameworks should be controlled under a light microscope. The wide distribution of the measured marginal discrepancies may be attributed to difficulties during scanning, digitization and preparation of long-span FPDs milled from brittle ceramic materials. Therefore, further developments of the Precident DCS system should lead to better adaptation to the CAD/CAM processing of alumina- and zirconia-based ceramics.

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# Effects of Different Burs on Dentin Bond Strengths of Self-Etching Primer Bonding Systems

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**Clinical Relevance**

Selecting a bur for cavity preparation is an important factor for improved bonding of adhesive systems using self-etching primer to dentin.

**SUMMARY**

**This study evaluated the effects of cutting dentin with different types of burs on tensile bond strength using three self-etching primer bonding systems (Clearfil Liner Bond 2 [LB2], Clearfil Liner Bond 2V [2V] and Clearfil SE BOND [SE], Kuraray, Co, Ltd, Osaka, Japan). Thirty-six intact extracted human third molars were ground flat to expose occlusal dentin, followed by polishing the dentin surfaces with #600 SiC paper. The teeth were divided into four groups according to bur type and grit: fine cut fissure steel bur (SB600), cross cut fissure steel bur (SB703), regular grit diamond bur (DB). Controls were abraded with #600 grit SiC paper (AP#600). The dentin surfaces of the SB600, SB703 and DB groups were cut under copious air-water spray with the respective burs mounted in a dental handpiece. The teeth were treated with one of three adhesive systems, then composite buildups were created with Clearfil AP-X (Kuraray Co, Ltd, Osaka, Japan). After soaking in water at 37°C for 24 hours, serial vertical sections (0.7 mm thick, 7-8 slices per one tooth) were made, trimmed to form an hour-glass shape with a 1.0 mm² cross-section and tensile bond strengths were determined at a cross-head speed of 1 mm/min. Statistical analysis was made using one and two-way ANOVA and Fisher's PLSD test ($p<0.05$). Eight additional molars were prepared. Burs or abrasive paper were used for SEM observations of the dentin surfaces of each group before and after treatment with the self-etching primers. All adhesive systems yielded the same ranking of bond**

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**strengths to the surfaces prepared with different abrasives: from highest to lowest, AP#600 > SB600 > SB703 > DB. This ranking reached statistical significance using Clearfil Liner Bond 2V (p<0.05). Therefore, when cutting dentin, selecting the adequate bur type is important for improved bonding of adhesive systems using self-etching primer to dentin.**

## INTRODUCTION

Many *in vitro* studies regularly report high bond strengths of newly developed dentin bonding systems (Harada & others, 2000, Ogata & others, 2001). Most of these laboratory-bonding studies prepare the dentin surfaces by using silicon carbide abrasive papers, whereas clinics routinely use different cutting instruments such as diamond or steel burs. Therefore, information on the effects of cutting dentin with different burs on resin-dentin bond strength is essential for appropriate clinical use of dentin bonding systems. After mechanical preparation of the cavity with a dental instrument such as a bur, an amorphous layer of organic and inorganic debris, the so-called smear layer, is formed on the surface (Pashley, 1984). It is well known that the quantity and quality of the smear layer varies widely depending on the manner in which they were created (Eick & others, 1970, Gilboe & others, 1980). Differences in smear layers prepared with bur cutting or abrasive paper have been reported to affect the bond strengths of resins to dentin (Tagami & others, 1991, Watanabe & others, 1994a). Sekimoto, Derkson & Richardson (1999) also suggested that dentin-bonding systems may have reduced effectiveness when the dentin has been cut with burs.

Self-etching primers contain an acidic resin monomer. When self-etching primers are applied to the smear layer-covered tooth surface, these acidic primers simultaneously modify or dissolve the smear layer and decalcify both the enamel and dentin surfaces (Watanabe & others, 1994b). It has been reported that adhesive systems using self-etching primer produce good adhesion to enamel and dentin (Barkmeier, Los & Triolo, 1995; Kanemura, Sano & Tagami, 1999; Harada & others, 2000). These systems have also been reported to demonstrate excellent clinical performance and high retention rate in clinical situations (Latta & others, 1997). On the other hand, Toida, Watanabe & Nakabayashi (1995) reported that tensile bond strength of the self-etching primer bonding system to dentin surfaces prepared by burs was lower than for those prepared by #600 silicon carbide abrasive paper. To obtain more reliable, higher bond strengths, they concluded that the rough and thick smear layer created with burs should be removed with acid etching.

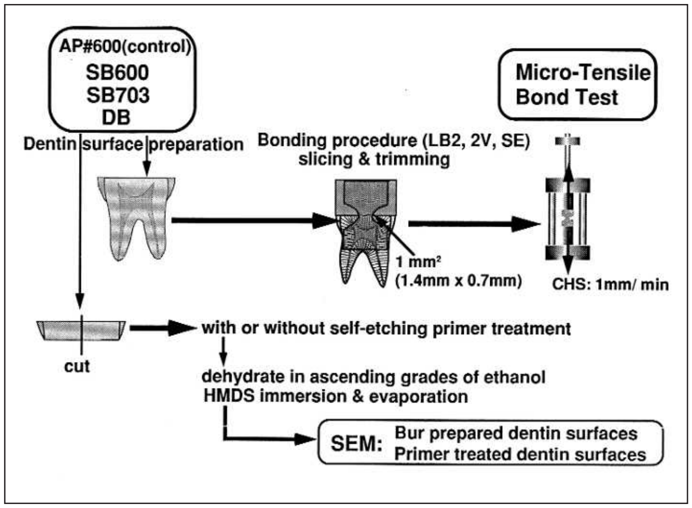


Figure 1. *Schematic showing the specimen preparation method used for tensile bond strength testing, SEM observations of the dentin surfaces prepared with the burs or abrasive paper, and SEM observation of the dentin surfaces of each group treated with the self-etching primers.*

This study evaluated the effects of cutting dentin with burs of different types and grits on tensile bond strength using three commercially available adhesive systems using self-etching primer. The null hypothesis was that different surface preparation methods would have no effect on resin-dentin bond strength.

## METHODS AND MATERIALS

Figure 1 illustrates the specimen preparation method used for tensile bond strength testing and SEM observation. Thirty-six frozen extracted caries-free human third molars were thawed and used for micro-tensile testing (Sano & others, 1994). The occlusal enamel was removed perpendicular to the long axis of the tooth by means of a model trimmer under running water, and a flat dentin surface was polished with #600 SiC abrasive paper under running water. The teeth were then divided into four groups (nine teeth for each group) according to bur types and grits as shown in Table 1. Number 1 represents a fine cut 12 blade tapered fissure steel bur (SB600 group), Number 2 represents a cross-cut tapered fissure steel bur (SB703 group), Number 3 represents a regular grit diamond bur (the average diamond particle size: 100 µm) (DB group) and Number 4 represents a control surface abraded with 600 grit SiC paper (AP#600 group). The dentin surfaces of the SB600 and SB703 groups were cut with respective steel burs mounted in a straight micromotor handpiece (INTRAmatic LUX2 10LN, Kavo, Germany) at 2000 rpm. The teeth in DB group were cut with a diamond bur mounted in a dental turbine (SUPER TORQUE LUX2 640B, Kavo, Germany) at 100,000~120,000 rpm. The same operator prepared the teeth for 30 passes across the dentin surfaces by bur under copious air water spray until the uniform scratches by each bur were made on the whole dentin surface. For the AP#600 group, the teeth were prepared by using 20 strokes of 15 cm length on #600-grit SiC paper under running water with hand pressure.

After preparation of the dentin surfaces, all teeth were treated with one of the three adhesive systems shown in Table 2 (three teeth for each bonding system) according to the manufacturers' recommendations. After each adhesive resin was light cured, a resin composite (Clearfil AP-X, Kuraray Co, Ltd, Osaka, Japan) was built incrementally up to a height of 5 mm to ensure sufficient bulk for the micro-tensile bond test (Sano & others, 1994). After light curing, the specimens were stored in 37° water for 24 hours.

The resin-bonded teeth were then serially sectioned into 7-8 slices parallel to the long axis of the tooth approximately 0.7 mm thick using a low-speed diamond saw (Leitz 1600 Microtome, Leica Instruments GmbH, Heidelberg, Germany) under water cooling. The bonded areas were isolated using a superfine diamond bur (c16ff, GC Ltd, Tokyo, Japan) to create an hourglass configuration with a cross-sectional area of approximately 1 $mm^2$. The final width and thickness of the bonded area were measured by means of a digital caliper to adjust the raw bonding data to an equalized bond/1 $mm^2$. The specimens were then attached to the testing device (Bencor-Multi-T, Danville Engineering Co, San Ramon, CA, 94583) with a cyanoacrylate adhesive (Zapit, Dental Ventures of America, Corona, CA, 91720), which in turn was placed in a table-top material tester (EZ-Test, Shimadzu Co, Kyoto, Japan) for tensile testing at a cross-head speed of 1 mm/min (Sano & others, 1994) (Figure 1). After the bond strengths were measured, all the specimens were visually and microscopically inspected (20x, DENTCRAFT DENT-OPTIC DX, Yoshida, Tokyo, Japan) to determine the modes of fracture. In addition, representative samples were observed using a scanning electron microscope (JXA-840, JEOL, Tokyo, Japan) to confirm the accuracy of the visual inspection.

Statistical analysis of the tensile bond strengths were performed using one-way and two-way ANOVA and Fisher's PLSD test at 95% level of confidence.

Eight additional third molars were used for SEM observation of the dentin surfaces prepared with the burs or abrasive paper before and after treatment with the self-etching primers. Flat dentin discs with a thickness of approximately 1 to 1.5 mm were cut perpendicularly to the long axis

Table 1. *Identification of Groups by Dentin Surface Preparation*

| Group | Method for Preparation | Manufacturer | RPM |
|---|---|---|---|
| AP#600 | #600 silicon carbide paper | Marumoto Struers Tokyo, Japan | - |
| DB | Diamond point, FG-REGULAR, #103 (average diamond particle size: 100 μm) | Shofu, Kyoto, Japan | 100,000~120,000 rpm |
| SB600 | Fine cut tapered fissure steel bur, #600 (12 blades) | Hager & Meisinger, Dusseldorf, Germany | 2,000 rpm |
| SB703 | Cross cut tapered fissure steel bur, #703 (6 blades) | Dentech, Tokyo, Japan | 2,000 rpm |

Table 2. *Adhesive Systems Used for Bonding*

| System | Ingredients | Primer pH | Procedures | Manufacturer |
|---|---|---|---|---|
| Clearfil Liner Bond 2 (LB2) | | | | |
| LB-primer A | Phenyl-P, 5-NMSA, ethanol, photoinitiator, accelerators | 1.51(A+B) | a; b (30 seconds); | Kuraray, Osaka, Japan |
| LB-Primer B | HEMA, water | | c; d (20 seconds) | |
| LB-Bond | MDP, HEMA, Bis-GMA, microfiller, photoinitiator, accelerators | | | |
| Clearfil Liner Bond 2V (2V) | | | | |
| Primer Liquid A | MDP, HEMA, water, photoinitiator, accelerators | 3.03(A+B) | a; b (30 seconds); | Kuraray, Osaka, Japan |
| Primer Liquid B | HEMA, water, initiator | | c; d (20 seconds) | |
| Bond Liquid A | MDP, HEMA, Bis-GMA, microfiller, photoinitiator, accelerators | | | |
| Clearfil SE BOND (SE) | | | | |
| Primer | MDP, HEMA, water, multifunctional methacrylate, photoinitiator | 2.04 | b (20 seconds); c; d (10 seconds) | Kuraray, Osaka, Japan |
| Bond | MDP, HEMA, multifunctional methacrylate,microfiller, photoinitiator | | | |

Procedures: (a) mix primer; (b) apply primer; (c) apply adhesive; (d) light-cure of the tooth by means of a low-speed diamond saw (Leitz 1600 Microtome, Leica Instruments GmbH, Heidelberg, Germany) from the mid-coronal part of the teeth. Each disk was cut into halves. Four half-discs were used for each group (SB600, SB703, DB or AP#600). Dentin surfaces were prepared with burs or silicon carbide paper, as was done for the dentin bond strength measurement described above. For the SEM observation of the degree of etching of these dentin surfaces, the surfaces of three of the four half-disks were treated with one of three self-etching primers. After each application time, the primer components were removed with 50% acetone/water solution (Harada & others, 2000). The fourth half-disk was used for observation of the smeared surface. All specimens were then dehydrated in ascending grades of ethanol (50%, 75%, 95% and 100% for 30 minutes), followed by immersion in hexamethyldisilazane [$(CH_3)_3SiNHSi(CH_3)_3$, HMDS, Pierce, Rockford, IL 61105, USA)] for 10 minutes, placed on a filter paper inside a covered glass vial and air dried at room temperature (Perdigão & others, 1995). The specimens were then gold sputter coated and observed with a scanning electron microscope (JXA-840, JEOL, Tokyo, Japan) at an accelerating voltage of 10 keV.

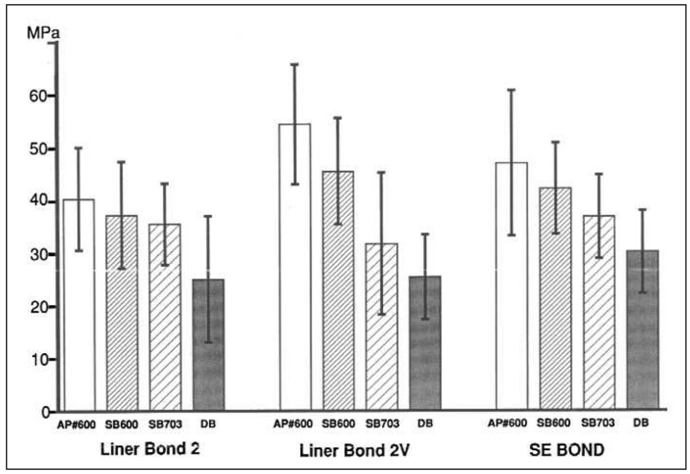


Figure 2. *Results of micro-tensile bond strengths for each group.*

## RESULTS

Figure 2 and Table 3 show the micro-tensile bond strength (µTBS) results of each group. All dentin surfaces prepared with #600 abrasive paper (AP#600 group) prior to the bonding procedure produced the highest (although not statistically significant) tensile bond strengths (LB2: 40.4±9.7 MPa; 2V: 54.4±11.3 MPa; SE: 47.0±13.7 MPa). On the other hand, the DB group resulted in significantly lower bond strengths than those of the AP#600 group (LB2: 25.1±12.0 MPa; 2V: 25.5±8.1 MPa; SE: 30.2±7.9 MPa). For all adhesive systems, groups with bond strengths from highest to lowest were AP#600 > SB600 > SB703 > DB. There were statistically significant differences among the groups when the dentin surfaces were treated with 2V

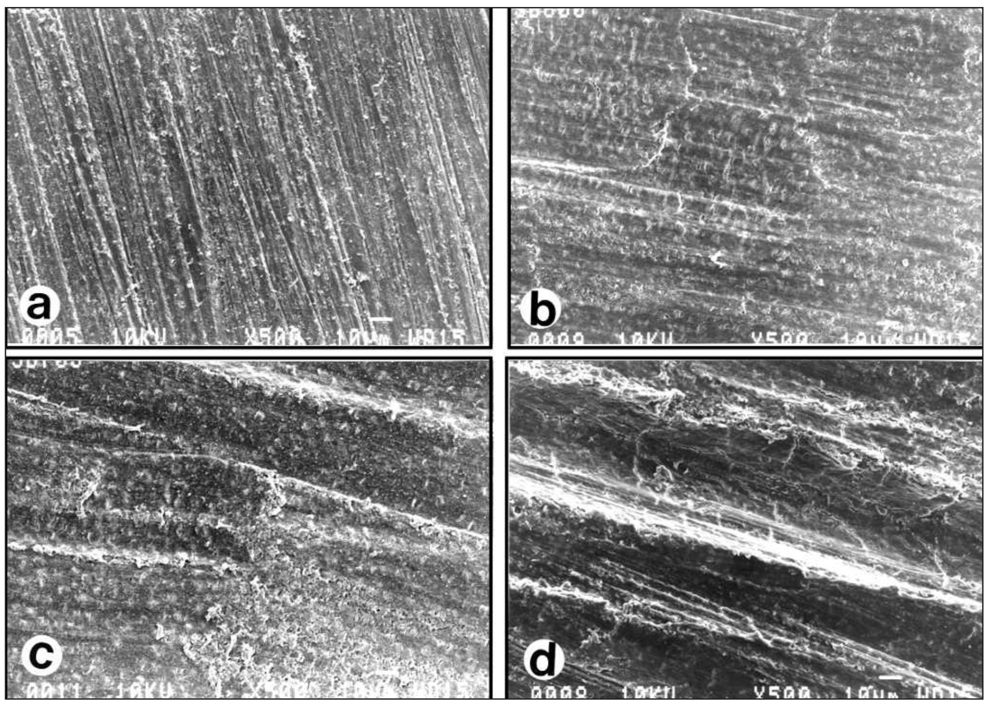


Figure 3. *SEM of the prepared dentin surfaces of each group: A: AP#600 group; B: SB600 group; C: SB703 group; D: DB group (original magnification 500x; bar = 10 µm).*

Table 3. *Results of Micro-Tensile Bond Strengths for Each Group (mean ± SD) (MPa)*

| | Liner Bond 2 | Liner Bond 2V | SE BOND |
|---|---|---|---|
| AP#600 | 40.4 ± 9.7[ah] (n = 23) | 54.4 ± 11.3 (n = 19) | 47.0 ± 13.7[b] (n = 22) |
| SB600 | 37.3 ± 10.1[af] (n = 23) | 45.5 ± 10.0[gh] (n = 25) | 42.2 ± 8.6[bcfgh] (n = 24) |
| SB703 | 35.6 ± 7.7[ad] (n = 22) | 31.8 ± 13.5[d] (n = 22) | 36.9 ±7.9[cd] (n = 24) |
| DB | 25.1 ± 12.0[e] (n = 22) | 25.5 ± 8.1[e] (n = 22) | 30.2 ± 7.9[e] (n = 21) |

(n): number of the slabs tested. Groups that are not significantly different are marked with the same superscript letter (*p*>0.05).

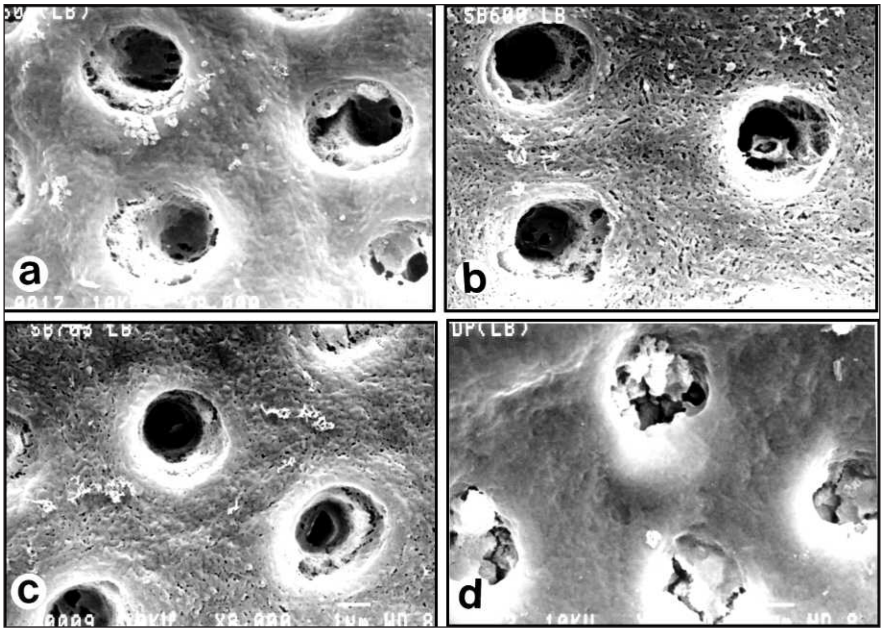


Figure 4. *SEM of Clearfil Liner Bond 2 primer treated dentin surfaces. A: AP#600 group; B: SB600 group; C: SB703 group; D: DB group (original magnification 8000x; bar = 1 µm).*

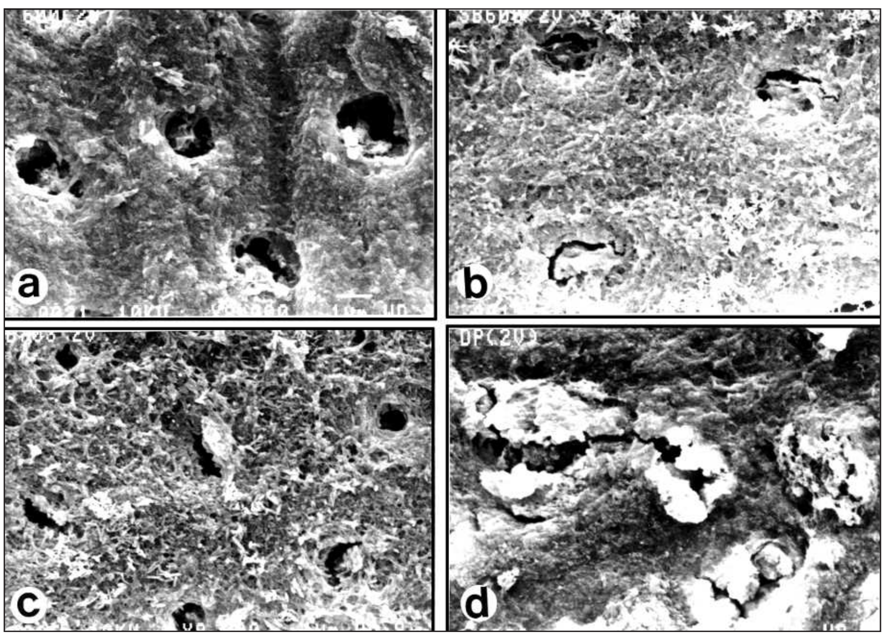


Figure 5. *SEM of Clearfil Liner Bond 2V primer treated surfaces: A: AP#600 group; B: SB600 group; C: SB703 group; D: DB group (original magnification 8000x; bar = 1 µm).*

($p<0.05$). Two-way ANOVA analysis revealed a statistically significant interaction between the bonding systems and the methods of dentin surface preparation ($p=0.019$).

When visually inspected, most specimens showed interfacial adhesive failure. This was confirmed by light microscopic examination (20x). The representative micromorphology of the failure pattern was classified as mixed failures within the dentin and bonding resin. There was no remarkable difference in the failure patterns among all the groups.

Scanning electron micrographs of each prepared dentin surface are shown in Figure 3, and micrographs of the prepared dentin surface treated with each self-etching primer are shown in Figures 4-6. For the groups AP#600, SB600 and SB703, the dentin surfaces revealed many scratches left by the abrasive paper or burs, and the surfaces were completely covered with smear layer. Dentinal tubules occluded by the smear plugs were also observed over the entire surface (Figure 3 A-C). The SEM observation of the dentin surface of the DB group demonstrated that grooves left by the bur were coarser than the other groups (Figure 3D). An irregular thick smear layer without any evidence of underlying dentinal tubules was seen on the top of the grooves, while dentinal tubules occluded by the smear plugs were observed at the bottom of the grooves (Figure 3D). When the self-etching primers were rinsed from the prepared dentin surfaces using 50% acetone-water, the extent of etching was revealed. For the AP#600, SB600 and SB703 groups of the LB2 primer treated surface and the AP#600, SB600 groups of the SE primer treated surface, the smear layer on the dentin surface and the smear plugs in the dentinal tubules were removed. For these groups the intertubular dentin and the peritubular dentin of the tubule orifices were slightly etched and the edge of the dentinal tubules were clearly observed (Figures 4 A-C, 6A,B). For the DB group treated with LB2 and SE, the smear layer on the dentin surface was removed but the dentinal tubules remained occluded by residual smear plugs (Figures 4D, 6D). For the AP#600 group treated with 2V, the smear layer on the dentin surface was removed. However, residual smear plugs were still within the dentinal tubules even though much of the peritubular dentin matrix was removed, thereby enlarging the tubule orifices (Figure 5A). For the SB600 and the SB703 groups treated with 2V, the tubule orifices were evident but not enlarged and occluded with residual smear plugs (Figure 5B,C). For the DB group treated with 2V, the dentin surface

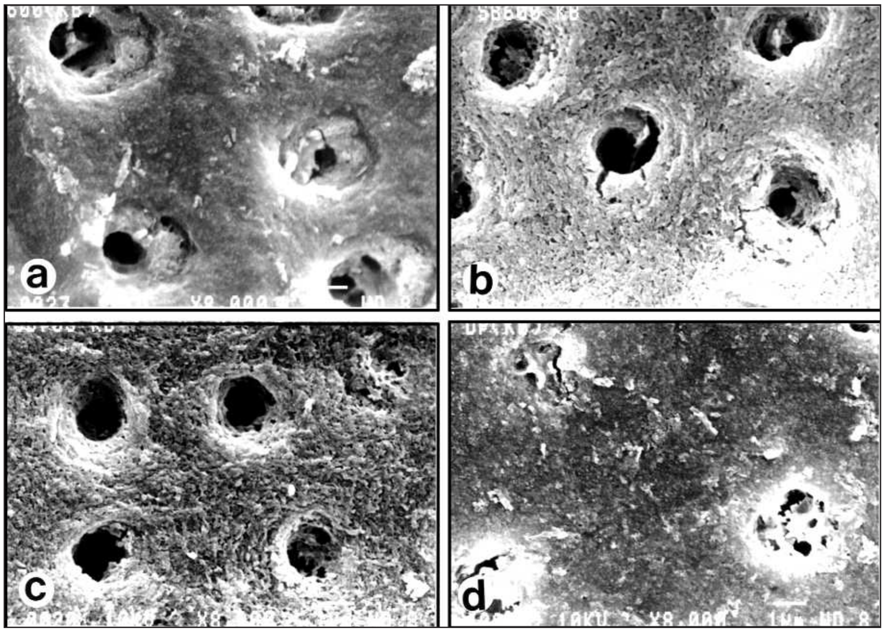


Figure 6. *SEM of Clearfil SE BOND primer treated surfaces: A: AP#600 group; B: SB600 group; C: SB703 group; D: DB group (original magnification 8000x; bar = 1 µm).*

remained covered with a great amount of smear layer (Figure 5D).

## DISCUSSION

Self-etching primers combine the etching and priming steps into one procedure. The self-etching primers are applied to smear-layer covered dentin, followed by brief air drying and application of the bonding resin. The manufacturers' instructions specify that the primed surface should not be rinsed with water. Therefore, the self-etching primers' acidic component demineralize through the smear layer and diffuse a short distance into the underlying dentin, resulting in the creation of a thin hybrid layer with strong bonds to dentin (Watanabe & others, 1994b; Chigira & others, 1994). The self-etching primers disclose less etching ability because of their relatively high pH (1.51~3.03,Table 2) when compared with phosphoric acid etchants' pHs between (3M Scotchbond Etchant (35% phosphoric acid) = 0.6, information from the manufacturer). Therefore, it is believed that the bond strengths of self-etching primer bonding systems to dentin could be affected by differences in the quantity and quality of the smear layer because of the weak acidity of self-etching primers. Watanabe & others (1994a) reported that the dentin bond strengths of an experimental self-etching primer bonding system (self-etching primer: aqueous solution of 20% Phenyl-P and 30% HEMA; bonding resin: 5% Phenyl-P in TEGDMA) were affected by the different smear layers created by the different grits of abrasive papers. Toida & others (1995) reported that the tensile bond strengths of the same system used by Watanabe & others (1994a) to dentin prepared with diamond or steel burs were significantly lower than those to dentin prepared with #600-grit abrasive paper. On the other hand, Akimoto & others (1999) reported that the micro-tensile bond strengths of Liner Bond 2V and Clearfil SE Bond were not affected by the dentin surface condition. They bonded to dentin surfaces prepared with #180 or #600-grit abrasive papers versus mirror-like surfaces of dentin. In this study, the dentin surfaces were prepared with an abrasive paper or different types of burs, and the micro-tensile bond strengths of the LB2, 2V and SE were shown to be affected by dentin surface condition. The tensile bond strength of these adhesive systems to the bur-prepared dentin surfaces were lower than those to the #600-grit abrasive paper prepared dentin surfaces. For all adhesive systems, the DB group resulted in significantly lower bond strengths ($p<0.05$) than those of the AP#600 group. The quality and quantity of the smear layer created by the bur cutting should be different from that created by the #600-grit abrasive paper. Indeed, it was reported that the smear layer created by diamond or steel bur was coarser, and its mechanical properties weaker than that created by the #600-grit abrasive paper (Toida & others, 1995). The SEM observations of the dentin surface of the DB group demonstrated that grooves left by the bur were coarser than those seen in the other groups. Bands of the dentin surface were completely covered with an irregular, thick smear layer that alternated with bands in which the dentinal tubules occluded by the smear plugs could be observed (Figure 3D). This distinct structure of the smear layer of the DB group might contribute to the decrease in bond strengths seen in this group when treated with all of the adhesive systems (Figure 2, Table 3).

For the AP#600 group, 2V produced highest bond strength among the three adhesive systems. However, this high bond strength significantly decreased when the dentin surfaces were prepared with the burs. Ranking of bond strengths from highest to lowest yielded the following results: AP#600 > SB600 > SB703 > DB. This order was common to all adhesive systems and among all groups treated with 2V, statistically significant differences existed ($p<0.05$). For the AP#600 group, SEM observation of primer-treated dentin surfaces demonstrated that the smear layer on the dentin surface was removed by primers of all adhesive systems (Figures 4A, 5A, 6A). For the LB2 and SE primed-surfaces of this group, the smear plugs were removed, the intertubular dentin and the peritubular dentin of the tubule orifices were slightly etched and the edges of the dentinal tubules were clearly observed (Figures 4A, 6A). On the other hand, for the DB group treated with Clearfil Liner Bond 2, the SB600, SB703 and DB groups treated with Clearfil Liner Bond 2V and the DB group treated with Clearfil SE BOND, which revealed significantly lower bond strengths than the AP#600 group, the dentinal tubules remained occluded by residual smear plugs and the intertubular dentin surface remained covered with smear layer (Figures 4D, 5B-D, 6D). These structural differences of primer-treated dentin surfaces seem to reflect the difference in the demineralization effect that is due to the pH of the self-etching primers. The pH of the primers was 1.51 for LB2 (primer A+B), 3.03 for 2V (primer A+B) and 2.04 for SE. Clearfil Liner Bond 2 primer contains the acidic monomer Phenyl-P (2-methacryloyloxyethyl phenyl phosphate). The manufacturer reformulated the Clearfil Liner Bond 2V primer by substituting MDP (10-methacryloxydecyl dihydrogen phosphate) for Phenyl-P. Since the pKa of MDP is higher than that of Phenyl-P, Clearfil Liner Bond 2V primer has a higher pH than Clearfil Liner Bond 2 primer (Nakajima & others, 1999). The difference in the quality and quantity of the smear layer created by the bur cutting may have strongly affected the bonding property of Clearfil Liner Bond 2V to dentin since the pH of this primer was milder than that of the other two primers. In spite of the smaller degree of demineralization, 2V provides good bond strength to AP#600-prepared dentin. One reason might be that the 2V primer, which contains MDP as an acidic monomer and chemical polymerizing catalyst, successively penetrated into the mildly demineralized collagen network. Then, the polymerized primer and bonding resin created a thin hybrid layer (1µm), contributing to the improvement of the bond strength (Harada & others, 2000).

When the dentin surfaces were cut by different burs, some smear layers which could not be completely demineralized or removed by self-etching primers remained on the dentin surface. Thus, demineralization of the underlying dentin and further penetration of the bonding resin into the demineralized dentin could have been compromised. This may explain why the bond strengths to dentin prepared by burs decreased, especially for the DB group. Therefore, selection of the bur for cutting the dentin surface for direct resin composite restoration is important for producing optimal bonding of self-etching primer bonding systems to dentin. Cutting the dentin surface with regular grit diamond burs should be avoided or followed with finishing the cavity surface with steel burs when bonding with self-etching primer bonding systems. Clinically, the initial opening of a carious cavity is done with diamond or carbide burs and is generally followed by removing carious dentin with round steel burs (Fusayama, 1980). In this study, the SB600 groups of all adhesive systems produced relatively high tensile bond strengths among the groups which used the bur (groups SB600, SB703, DB). Therefore, by using steel burs at low speed, relatively high bond strengths could be expected for clinical use of these adhesive systems.

The high speed turning of the bur induces increased thermal and mechanical stress. An abrading cutting instrument such as a diamond bur creates more frictional stress when compared to a cutting instrument like a steel bur. Actually, during cavity preparation for direct composite resin restoration, diamond burs are often used to open and rough out of the cavity at high speed and low speed steel burs excavate carious dentin. Since the steel burs were used at low speeds and the diamond bur used at high speed, it is unclear whether the lowest bond strengths were due to high speed, diamond bur or both. The final result is reduced bond strength when using self-etching primers. Further research is necessary to isolate the exact cause of that effect.

In a prior study of regional bond strengths to cervical wedge-shaped cavities using self-etching primer bonding systems, the authors reported the bond strengths of Clearfil Liner Bond 2 improved when multiple layers of LB-primer were applied to the cavity without expending the application period recommended by the manufacturer (Ogata & others, 1999). The multiple primer application method supplied adequate amounts of primer into a wedge-shaped defect to replace primer that flows off the walls due to gravity. In that study, multiple layers of LB-primer completely dissolved the smear layer and the bonding resin penetrated more deeply into the demineralized dentin. Multiple primer application might overcome the resistance of bur-created smear layers to the etching effects of these primers, leading to improvement of the bonding property of these systems.

Most clinically prepared cavities include regions of normal and sclerotic or caries-affected dentin. The chemical composition of smear layers may change due to the structure from which they are formed (Pashley, 1992). Kimochi & others (1999) suggested that the amorphous structure that was observed on the surface of the caries-affected dentin may inhibit hybrid layer formation by self-etching primer bonding systems. According to their study, the micro-tensile bond strengths of Clearfil SE Bond to caries-affected dentin showed significantly lower values than that of normal dentin. Nakajima & others (1999) reported that the micro-tensile bond strengths of Clearfil Liner Bond 2 and Clearfil Liner Bond 2V to caries-affected dentin showed significantly lower values than that of normal dentin. The difference between caries-affected and normal dentin was not found when the substrates were acid-etched with 32-35% phosphoric acid and bonded with single bottle adhesives (Nakajima & others, 2000). Thus, development of bonding resins and procedures that produce high, uniform bond strengths to all types of dentin, whether normal or abnormal, as well as the various types of smear layers prepared in various ways, has still not been achieved. More research needs to be done on clinically relevant dentin substrates using clinically relevant surface preparations (that is, high speed vs low-speed burs). The results of this study do not support the hypothesis that dentin preparation with different burs has no effect on resin-dentin bond strength using self-etching primers.

## CONCLUSIONS

All self-etching primer bonding systems used in this study disclosed the significantly highest tensile bond strengths for the AP#600 group and the significantly lowest bond strengths for the DB group. Groups with bond strengths from highest to lowest were AP#600 > SB600 > SB703 > DB for all adhesive systems. There were statistically significant differences among all groups when the dentin surfaces were treated with 2V ($p<0.05$). Selection of the bur for cavity preparation is an important factor for improved bonding of adhesive systems using self-etching primer to dentin.

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# Microleakage in Amalgam Restorations: Influence of Cavity Cleanser Solutions and Anticariogenic Agents

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### Clinical Relevance

Solutions used to treat cavity preparations do not influence the microleakage of amalgam restorations, except for sodium hypochlorite in enamel.




## SUMMARY

**This study evaluated** *in vitro* **the influence of five solutions used to treat cavity preparations on microleakage of amalgam restorations. Seventy-two standard Class V cavities were prepared in buccal and lingual surfaces of 36 recently extracted human third molars. The cervical wall was located in cementum and the occlusal wall was located in enamel. Specimens were randomly divided into six groups (n=12) according to the solution employed to treat the cavities: Group I–2.5% sodium hypochlorite; Group II–Calcium hydroxide solution; Group III–1.23% Acidulated phosphate fluoride; Group IV–2% digluconate of chlorhexidine; Group V–anionic detergent solution (1.25% sodium lauryl sulfate) and Group VI–control group. The solutions were applied for one minute, followed by washing and drying. Two coats of copal varnish were applied in each cavity. The cavities were filled with capsuled amalgam GS-80 (SDI). After finishing and polishing, the specimens were submitted for thermal cycling followed by immersion in methylene blue. Then, the specimens were sectioned and microleakage was evaluated based on a standard ranking under magnification (40x). Data were subjected to statistical analysis using non-parametric tests. Results of the study concluded that leakage was higher in cementum than enamel ($p<0.01$). The substances employed have no influence on microleakage except for sodium hypochlorite, which increased leakage values in enamel ($p<0.05$).**



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## INTRODUCTION

The smear layer is formed during cavity preparation when detritus, bacteria, oil, blood and other contaminants deposit over tooth structure (Pashley, 1989). The presence of the smear layer may interfere with good adaptation between restorative materials and tooth structure. Also, since bacteria are present in this layer, some treatment must be performed prior to restorative procedures (Meiers & Shook, 1996). There is little evidence that cleansers and anticariogenic solutions could improve the performance of amalgam restorations. Alexander, McDonald & Stookey (1973) verified that applying fluoride prior to placing amalgam could reduce the occurrence of secondary caries, in a clinical evaluation. The objective is to reduce the risk of bacterial colonization, thus preventing damage to pulp tissue (Brännström & Vojinovic, 1976; Cox & others, 1987). When bacterial irritants are removed from the dentin, a moderate or severe pulp inflammation could be reversed (Bergenholtz, 1981). Several solutions have been suggested for this treatment.

Chlorhexidine solutions are the most widely used oral antiseptic. This is based on their low toxicity and high spectrum of antibacterial activity (Gjermo, 1989; Johnson, 1995). A 2% chlorhexidine solution to treat cavity preparation prior to restoration placement has been indicated. The antibacterial potential of this solution has already been proven (Chan & Nield, 1995). Its application does not impair the sealing ability and bond strength of adhesive materials (Perdigão, Denehy & Swift, 1994; Piva, Martos & Demarco, 1999; Kraul & others, 2000), although in specific situations some studies showed interference of chlorhexidine in adhesion (Meiers & Shook, 1996; Tulunoglu & others, 1998).

The higher critical pH in dentin compared to enamel (Hoppenbrouwers, Driessens & Borggreven, 1987) and the diffusion of acids to dentinal tubules make dentin more susceptible to demineralization (ten Cate, Damen & Buijs, 1998). However, the high percentage of fluoride uptake by dentin and formation of a higher mineralized superficial layer (ten Cate, Damen & Buijs, 1998) can justify applying fluoride to cavity walls. Alexander & others (1973) have demonstrated the preventive effects of fluoride application over secondary caries developing in amalgam restorations. Several authors have recommended such treatment (Baratieri, 1993; Donly, Stufflebeam & García-Godoy, 1998; Pimenta & others, 1998).

Sodium hypochlorite showed an antibacterial effect due to the release of oxygen and chloride when in contact with organic substrate. Also, the high pH (11.8) neutralizes the acidified cavity, creating a hostile medium for bacteria. Recently, Akimoto & others (1998) have suggested applying sodium hypochlorite to disinfect and control bleeding when adhesive pulp capping occurs. According to these authors, sodium hypochlorite is not toxic to cells and does not impair pulp healing.

Mondelli & others (1983) indicated the use of an aqueous solution of calcium hydroxide to wash the cavity preparation for amalgam restorations. This relates to the ability of calcium hydroxide to increase the pH, thus creating a more favorable medium for pulp-dentin complex repair.

Anionic detergent solution has been largely employed as a cleaning solution prior to amalgam condensation. A solution of sodium lauryl sulfate can reduce the superficial tension from liquids, and it maintains the residues that result from the cavity preparation in suspension without antibacterial activity (Mondelli, 1998).

Topical application of fluoride forms a precipitate of calcium fluoride (Fejerskov, Thylstrup & Larsen, 1981) in the cavity, which could serve as a reservoir against cariogenic challenge (Pimenta & others, 1998). Chlorhexidine creates a strong electrostatic link to hyhdroxyapatite (Sodhi, Grad & Smith, 1992). The application of an aqueous solution of calcium hydroxide originates soluble aggregates over the smear layer (Mondelli, 1998). Calcium hydroxide may also be solubilized by copal varnish (Ben-Amar & others, 1985). The formation of soluble precipitates could originate an altered smear layer that may have some interference on microleakage.

The hypothesis to be tested is whether different substances used to treat the cavity preparation could influence microleakage in amalgam restorations.

## METHODS AND MATERIALS

Thirty-six human third molars were selected. The teeth were recently extracted for orthodontic reasons. They were examined under magnification to ensure that they were free of fractures or structural defects. Prior to any procedure, the teeth were cleaned, autoclaved and maintained in saline solution until testing.

Standard small Class V cavities were prepared in buccal and lingual surfaces using a #245 carbide bur under air-water cooling. Burs were replaced after five preparations to ensure high cutting capacity. One operator performed all preparations. The cervical wall was located in cementum and the occlusal wall was located in enamel. Specimens were randomly divided into six groups (n=12) according to the substances applied. The materials tested are presented in Table 1. All materials were applied in the same methodology, that is, after preparation, the cavities were copiously washed with water. Following drying, different substances—chlorhexidine, fluoride, sodium hypochlorite, anionic detergent and aqueous solution of calcium hydroxide—were applied for 60 seconds using a MicroBenda Brush (Centrix, River Road, Shelton, CT 06484). After washing with water (15 seconds) and drying (10 seconds), two coats of copal varnish (Macroquimica, Porto Alegre, Brazil, 015) were applied in the entire cavity preparation. The group with only copal varnish application served as the control. Admixed capsuled amalgam GS-80 (Southern Dental Industries, Baywater, Victoria, 3153, Australia 709154) was used to fill the cavities. Amalgamator

Table 1: *Solutions Employed in Each Group*

| | Cleansers and Anticariogenic Agents Employed |
|---|---|
| Group I | 2.5% sodium hypochlorite prepared solution |
| Group II | Aqueous solution of calcium hydroxide (19 g in 100 ml of distilled water) |
| Group III | 1.23% Acidulated phosphate fluoride gel (Nupro, Dentsply LTDA, Petrópolis, RJ, Brazil) |
| Group IV | 2% Chlorhexidine digluconate Cav-Clean (Herpo, Dentsply, Petrópolis, RJ, Brazil, 66083) |
| Group V | 1.25% Sodium lauryl sulfate - detergent solution (Tergipol – Biodinâmica, Ibiporâ, PR, Brazil). |
| Control | No substance was applied prior to copal varnish |

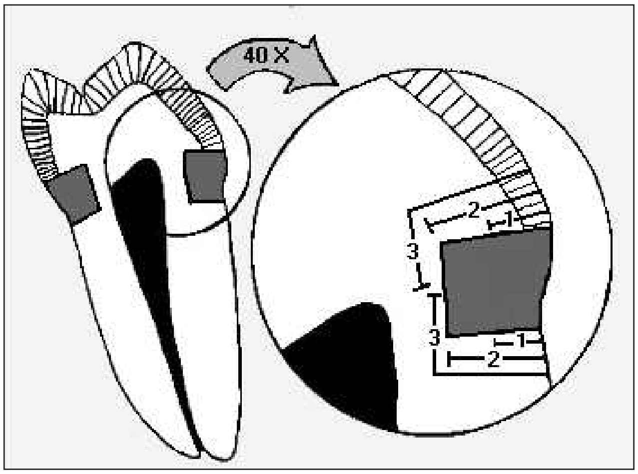


Figure 1. *Standard scores for microleakage evaluation: 0–No leakage; 1–Leakage up to 1/2 of the cavity preparation depth; 2–Leakage higher than 1/2 of the preparation depth; 3–Leakage arrived to the floor of the cavity.*

Ultramat 2 (Southern Dental Industries, Baywater, Victoria 3153, Australia) was set to 4,600 rpm for eight seconds. The amalgam was condensed in two horizontal increments using Ward and Hollenback condensers. Carving was performed using Hollenback 3S. After 24 hours, the restorations were finished and polished.

The specimens were kept in distilled water for seven days at 37°C. They were then submitted for 500 cycles of thermal cycling between 5°C and 55°C with a dwell time of one minute. The apex was sealed using composite and epoxy resin. All the teeth were painted with two-coats of nail varnish, except for the restorations and 2 mm around them. Specimens were immersed in 2% methylene blue for 24 hours, then washed in tap water for 12 hours. Following removal of the nail varnish, the specimens were sectioned using a diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL 60044), and three examiners assessed the leakage under magnification (40x) based on a standard ranking (Figure 1). Data were subjected to statistical analysis using non-parametric Mann-Whitney and Kruskal-Wallis tests.

## RESULTS

Tables 2 and 3, respectively, show microleakage scores in enamel and cementum/dentin margins.

Statistical analysis of leakage in enamel using non-parameric Kruskal-Wallis disclosed that sodium hypochlorite demonstrated higher leakage than the control group ($p<0.05$), with all others groups being similar (Table 2).

Using Kruskal-Wallis, no statistical differences were found among the different groups in cementum-dentin margins (Table 3).

Comparing cementum-dentin and enamel margins using non-parametric Mann-Whitney demonstrated leakage as being higher in cementum-dentin than in enamel ($p<0.01$).

## DISCUSSION

Amalgam has been the most employed restorative material in posterior teeth (Osborne, Chain & Chain, 1997). Despite the evolution in amalgam composition during the last century (Berry & others, 1998), marginal leakage still occurs. Lack of adhesion and thermal coefficient differences in the dental structure (Mahler & Bryant, 1996) may facilitate microleakage (Osborne, Chain & Chain, 1997; Marchiori & others, 1998). Microleakage can cause post-operative sensitivity and pulp pathologies (Brännstöm & Vojinovic, 1976; Pashley, 1991), leading to secondary caries, which is primarily responsible for restoration replacement (Allan, 1977; Mjör, 1981). Replacing restorations could increase cavity preparation, causing the loss of sound tooth structure (Mjör & others, 1998).

Different methods have been employed to disclose microleakage around restorations. Dye leakage is probably the most common method used. The principal advantages of this technique are its low cost and ease of application (Alani & Toh, 1997). Disadvantages include subjective evaluation of the results (Alani & Toh, 1997) and low molecular weight of the dye, which is smaller that that of bacteria. Also, tests using dyes could sometimes detect leakage where bacteria could not penetrate.

Any procedure that offers resistance to oral microorganism attack will improve clinical performance of restorations (Grossman & Matejka, 1996). Adhesive materials in bonded amalgam technique are another alternative to preventing microleakage. Cleanser and disinfecting agents can also increase the resistance of dental structure to bacterial colonization.

Copal varnish liners lack the ability to maintain long-term sealing. Such findings mainly result from their

Table 2: *Marginal Leakage in Enamel Margins for Different Groups*

| Groups | Scores | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| Control | 11 | 0 | 1 | 0 |
| NaClO* | 6 | 4 | 2 | 0 |
| $Ca(OH)_2$ | 9 | 1 | 2 | 0 |
| Chlorhexidine | 10 | 1 | 1 | 0 |
| 1.23% APF | 11 | 0 | 1 | 0 |
| Sodium Lauryl Sulfate | 10 | 1 | 1 | 0 |

(*) Sodium hypochlorite disclosed greater microleakage than control group ($p<0.05$), using Kruskal-Wallis non-parametric test. The others groups were similars to control group.

Table 3: *Marginal Leakage in Cementum/Dentin Margins for Different Groups*

| Groups | Scores | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| Control | 2 | 0 | 2 | 8 |
| NaClO | 1 | 0 | 1 | 10 |
| $Ca(OH)_2$ | 2 | 2 | 1 | 7 |
| Chlorhexidine | 2 | 2 | 1 | 7 |
| 1.23% APH | 1 | 0 | 4 | 7 |
| Sodium Lauryl Sulfate | 1 | 0 | 1 | 10 |

No statistical significant difference was found among tested groups ($p>0.05$), using Kruskal-Wallis non-parametric test.

solubility (Powell & Daines, 1987). Several studies have demonstrated better sealing by using adhesive materials instead of copal varnish under amalgam restorations (Pimenta & others, 1998; Sepetcioglu & Ataman, 1998; Marchiori & others, 1998).

In this study, higher leakage was disclosed in cementum-dentin than in enamel margins. These results relate to the morphologic composition of the tissue, which is more permeable. Dentin's great permeability to dyes has been reported as a confusing factor in microleakage testing at the cementum/dentin margin (Trowbridge, 1987; Gale & Darvel, 1999). Moreover, the small size of methylene blue particles (Alani & Toh, 1997) could provide higher penetration in cementum/dentin margins. Thus, a false positive result could be achieved in gingival margins of Class V cavities (Gale & Darvel, 1999). Therefore, dye penetration at the cementum/dentin interface may be a relative indicator of marginal leakage (Glyn & others, 1988). In enamel margins there is more confidence in the results because of the relative impermeability of this tissue (Gale & Darvel, 1999).

Similar to this study's findings, higher leakage of dye in the cementum/dentin margin than in an enamel margin was previously reported in the literature (Marchiori & others, 1998; Staninec & Holt, 1988; Toledano & others, 2000). No statistical difference in leakage was found among different groups in cementum/dentin margins. Then, the hypothesis tested was null, that is, no cleanser or disinfecting solution employed increased the leakage in relation to the control group.

In a previous study, Franscischone & others (1986) evaluated the influence of several cleanser agents on microleakage of amalgam restorations without thermal cycling methodology. Initial and 30-day microleakage was similar among the control and experimental groups. Such results confirm the results of this study.

In enamel, scores of leakage were minimal in most specimens, although thermal cycling was performed. Rossomando & Wendt (1995) observed a direct relation between leakage and thermal cycling for amalgam restorations, and they suggested that such findings could be caused by thermal conductivity of the material. Also, the volume of material employed could be an important reason for determining the performance of the restoration in relation to microleakage. In this study, the initial volume of the restorations was very small, probably when submitted to thermal cycling, smaller volumetric variation occurred, reducing gap formation and leading to lower leakage values. In addition, enamel is less permeable than dentin, producing a more resistant surface to dye penetration.

Cleanser and disinfecting solutions have no adverse effects on microleakage of amalgam restorations in enamel margins, except for 2.5% sodium hypochlorite. The properties of sodium hypochlorite are improved with the increase in concentration, exhibiting higher surface tension, higher wettability and higher residual effects. During this study the application of 2.5% sodium hypochlorite probably formed a film between the enamel and varnish, with low superficial tension and high surface energy. Thus, dye penetration could be facilitated even after air/water washing of the cavity, probably because of the residual effect of sodium hypochlorite. However, this can occur in the tooth/varnish interface due to the unbonded characteristic of copal varnish. In adhesive restorations, sodium hypochlorite did not impair marginal sealing as determined by Piva & others (1999) in a previous study.

Although the cleanser and disinfecting solution did not adversely influence microleakage of amalgam restorations, there is a need for additional studies investigating the ability of tested substances to clean and disinfect the pulp-dentin complex by preventing bacterial contamination.

## CONCLUSIONS

The cleanser and disinfecting agents employed in this study did not adversely affect the microleakage in amalgam restorations except for sodium hypochlorite in enamel margins.

The leakage in enamel was less than that from cementum/dentin margins.

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# Effects of Soft-Start Irradiation on the Depth of Cure and Marginal Adaptation to Dentin

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**Clinical Relevance**

For marginal integrity of resin composite restorations, the optimum combination of dentin bonding system and resin composite is more important than the irradiation method.

## SUMMARY

**Marginal adaptation of four resin composites, Clearfil APX, Estelite, Silux Plus and Z-100 cured with two irradiation methods (soft-start or high-power start) of a commercial soft-start halogen lamp unit (Elipar Highlight) were evaluated by measurement of the wall-to-wall contraction gap width. One-hundred and sixty cylindrical cavities, 3 mm in diameter and 1.5 mm in depth, were prepared in extracted human molars. The 80 cavity walls were treated with the Megabond system and each 20 cavities were filled with one of four resin composites. Then, each 10 fillings were irradiated by the soft-start method (soft-power light for 10 seconds followed by high-power light for 30 seconds) or high-power light for 40 seconds. The other 80 cavity walls were treated with an experimental bonding system consisting of 0.5M EDTA as a conditioner, 35% glyceryl mono-methacrylate as a primer and Clearfil Photo Bond as a bonding agent. The cavities were restored wtih the four resin composites and two irradiation methods, the same as the Megabond group. The contraction gap was measured with a light microscope and expressed in % of the cavity diameter. In addition, the curing capability of these two light sources was evaluated by measurement of the curing depth of the four resin composites using a split Teflon mold 4 mm in inner-diameter and 8 mm in height. Marginal gap formation of Clearfil APX, Estelite and Silux Plus with the experimental bonding system was completely prevented regardless of the kind of irradiation methods used. The deterioration of marginal adaptation caused by the Megabond system could not be improved by use of the soft-start method programmed in Elipar Highlight.**

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## INTRODUCTION

It is essential to establish complete marginal adaptation of resin composite restoration to compensate for the quantity of polymerization contraction by the flow of resin composite from its free surface into the cavity during polymerization (Asmussen & Jørgensen, 1972; Davidson & de Gee, 1984a). The relationship between cavity adaptation and the velocity of polymerization of resin composites has been discussed; however, no consistent conclusions have been reported (Kato, 1987; Uno & Asmussen, 1991). The authors previously reported that delayed irradiation of a light cured resin composite caused deterioration of the marginal integrity in the dentin cavity probably because of the time lag of polymerization between the dentin bonding agent and the resin composite (Manabe & others, 1993). Therefore, the light cured resin composite should be irradiated sooner, possibly after being placed in the cavity. It has been revealed that dentin cavity adaptation of the light cured resin composite is inferior to that of auto cured resin composite because the light cured composite is rapidly polymerized by irradiation of a halogen lamp unit (Davidson, de Gee & Feilzer, 1984b; Itoh, Yanagawa & Wakumoto, 1986; Feilzer, de Gee & Davidson, 1993). Thus, contraction stress of the light cured resin composite is concentrated at the start of irradiation. It has been reported that methods to reduce the polymerization contraction stress include decreasing the power of the lamp unit or increasing the distance (Mehl, Hickel & Kunzelmann, 1997; Rueggeberg & Jordan, 1993) and neutral density filters (Sakaguchi & Berge, 1998) between the tip window of the light source and the resin composite. These techniques might be effective in improving the cavity adaptation of a resin composite. In addition, a soft-start lamp unit was introduced for polymerization of the resin composite. It was designed to automatically start irradiation with low power followed by high-power to reduce the initial contraction stress of the light cured resin composite. This study investigated the effect of soft-start irradiation on curing performance and cavity adaptation of resin composite restoration in dentin cavities.

## METHODS AND MATERIALS

### The Spectro-Photo Distribution Analysis

The halogen lamp units and dentin bonding systems tested are listed in Tables 1 and 2. Light intensities of the three lamp sources, the conventional light source of Witelite (Takarabelmont Co, Osaka 5420083 Japan), the soft-power light source and the high-power light source of Elipar Highlight (ESPE, Oberbay, Germany) were analyzed at regular wavelength intervals of one nanometer between a 200-nm and 800-nm wavelength using a multi-channel spectro-photo detector (MCPD-1000, Otsuka Electronics, Tokyo, 1920082 Japan) as shown in Figure 1. The relative light intensity was calculated as the proportion to light intensity at a wavelength of 480 nm for Witelite. The spectro-photo distribution of the light source was plotted by relative light intensity and a wavelength between 200 nm and 800 nm.

In addition, the light intensity of the three lamp sources mentioned above were also measured with a commercially available light meter, Apollo Meter (Hilux P/N: 950-700 #9020844; Dental Medical Diagnostic System Inc, Westlake Village, CA 91362) and Cure Rite (Model #644726-#5135; Dentsply Caulk, Milford, DE 19963) according to the manufacturer's instructions.

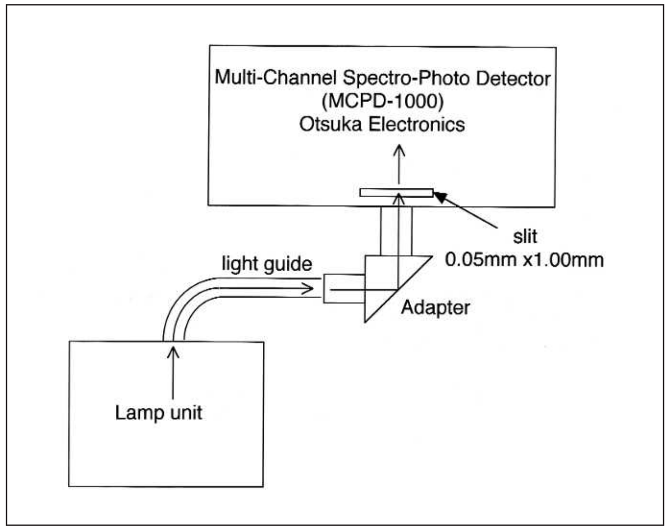


Figure 1. *Illustration of spectro-photo distribution analysis.*

Table 1: *Lamp Units*

| Lamp Unit | Manufacturer |
|---|---|
| Elipar Highlight | ESPE, Oberbay, Germany |
| Witelite | Takarabelmont Co, Osaka, 5420083 Japan |

Table 2: *Bonding Systems*

| Bonding System | Manufacturer | Batch |
|---|---|---|
| MEGA BOND | | |
| Primer | Kuraray, Osaka, 5300021 Japan | 00009A |
| Bond | Kuraray, Osaka, 5300021 Japan | 00017A |
| Experimental System | | |
| 0.5M EDTA | Experimental | |
| 35% GM solution | Experimental | |
| Clearfil Photo Bond | Kuraray, Osaka, 5300021 Japan | |
| Universal | | #389 |
| Catalyst | | #287 |

Table 3: *Commercially Available Resin Composites Employed in This Study*

| Resin Composite | Manufacturer | Batch |
|---|---|---|
| Clearfil APX | Kuraray, Osaka, 5300021 Japan | 0430 |
| Estelite | Tokuyama, Tokyo, 1500002 Japan | 1471 |
| Silux Plus | 3M Dental Products, St Paul, MN 55144 USA | 8AH |
| Z-100 | 3M Dental Products, St Paul, MN 55144 USA | 8EK |

Table 4: *Bonding Methods Employed in Contraction-Gap Study*

| Bonding Methods | Procedures |
|---|---|
| MEGA BOND | Primer for 20 seconds + dry + Bond + dry |
| Experimental | EDTA for 60 seconds + rinse & dry + GM for 60 seconds + rinse & dry + Clearfil Photo Bond + dry |

Table 5: *Light-Curing Methods Employed in Contraction-Gap Study*

| Light-Curing Methods | Irradiation Time for Bonding Agent | Irradiation Time for Resin Composite |
|---|---|---|
| Elipar Highlight at high power | 10 seconds high power | 40 seconds (40 seconds high power) |
| Elipar Highlight in soft-start mode | 10 seconds high power | 40 seconds (10 seconds low power & 30 seconds high power) |

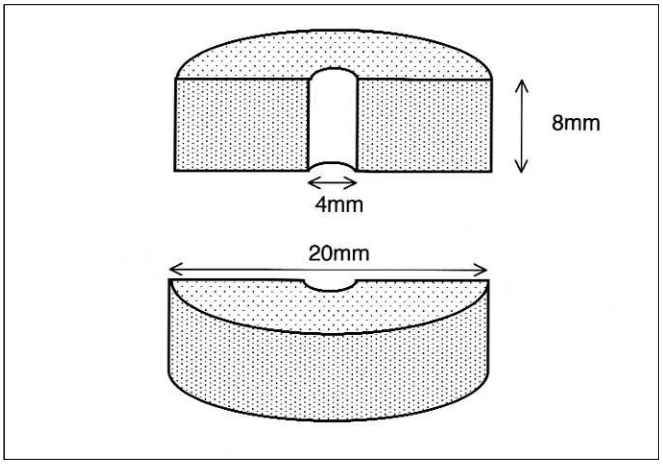


Figure 2. *Illustration of the split Teflon mold for curing depth study.*

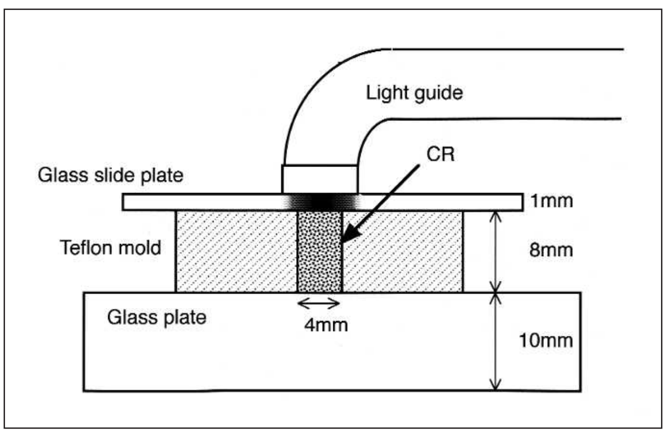


Figure 3. *Illustration of procedure for curing depth study.*

## Measuring the Curing Depth of a Resin Composite

The curing depths of resin composites irradiated by the Elipar Highlight soft-power light source or the high-power light source were measured using cylindrical specimens. The resin composite pastes listed in Table 3 were slightly over-filled in the cavity of the split Teflon mold 4 mm in inner diameter, 20 mm in outer diameter and 8 mm high, which was placed on a glass plate 10 mm in thickness (see Figure 2). The upper surface of the resin composite paste was covered and pressed gently by another glass plate 1 mm thick and irradiated by the soft-power light source for a maximum of 10 seconds or the high-power light source for a maximum of 20 seconds as shown in Figure 3. Immediately after finishing the irradiation, the cylindrical resin composite specimen was removed from the Teflon mold and the unpolymerized composite paste was eliminated by ethanol. The curing depth was determined by measuring the length along the long axis of the resin composite cylinder. Five specimens for each composite were prepared. The data were analyzed using ANOVA and Tukey's multiple comparison test at $a$=0.05 (Kleinbaum, Kupper & Muller, 1988) for each of the four composites at the light sources.

## Wall-to-Wall Contraction Gap Width Measurement

The effect of the irradiation mode on marginal adaptation of the resin composite was evaluated by measuring the wall-to-wall contraction gap width in a cylindrical dentin cavity. The evaluation of the bonding methods and light-curing methods are presented in Table 4 and Table 5. The proximal enamel of 160 extracted human molar were eliminated using wet carborundum paper grit #220, leaving a flat dentin surface. A cylindrical cavity, approximately 3 mm in diameter and 1.5 mm deep, were prepared in the exposed dentin. The first 80 cavity walls were treated with a commercial dentin bonding system (Megabond, Kuraray, Osaka, 5300021 Japan) according to the manufacturer's instructions. Subsequently, each 20 out of the 80 cavities were filled with one of four light-activated resin composites and the composite surface was momentarily pressed on a glass plate covered with a plastic matrix (Frasaco Polyester Strip, GC, Tokyo, 1740052 Japan). Ten out of the 20 resin fillings were then irradiated using the soft-start method (soft-power light for 10 seconds followed by high-power light for 30 seconds), while the other 10 resin fillings were irradiated with the high-power start method (high-power light for 40 seconds) of Elipar Highlight. After storing the specimen in water at a room temperature of 24 ± 1°C for 10 minutes, the excess resin composite was eliminated using wet carborundum paper grit #1000. The resin composite and surrounding dentin surfaces were polished on a linen cloth with a 0.03 µm alumina slurry. The marginal integrity of the composite restoration was inspected under a light microscope (Orthoplan; Leitz, Wetzlar, Germany), and the contraction gap width was measured at eight points every 45° along the cavity margin (see Figure 4). Contraction gap values were calculated by summing the diametrically opposite gap widths measured as a percent of the cavity diameter. The gap value of each specimen is reported as the maximum gap value of the four measured contraction gap values. For the control group, the second dentin cavity walls were pretreated by an experimental dentin bonding system, ensuring the prevention of any contraction gap of the light-activated resin composite (Silux Plus). The cylindrical dentin cavity was prepared as mentioned above and the cavity was conditioned with neutralized 0.5 mol/L EDTA solution (pH 7.4) for 60 seconds followed by rinsing and drying. Subsequently, the cavity was primed with an aqueous solution of 35 vol% glyceryl mono-methacrylate (Blemmer GLM, NOF Co, Tokyo, 1506019 Japan) for 60 seconds followed by air blasting. A commercial dual-cured dentin-bonding agent (Clearfil Photo Bond, Kuraray, Osaka, 5300021 Japan) was applied to the cavity walls and irradiated for 40 seconds after removing the excess materials with a gentle air blast. The gap width measurements were performed using the same method described previously. Then, each 20 out of 80 cavities were filled with the four resin composites and then 10 out of 20 resin fillings were irradiated using the soft-start method the same as the Megabond group. The data were analyzed by the Kruskal-Wallis and Mann-Whitney tests at a=0.05 (Siegel and Castellan, 1988).

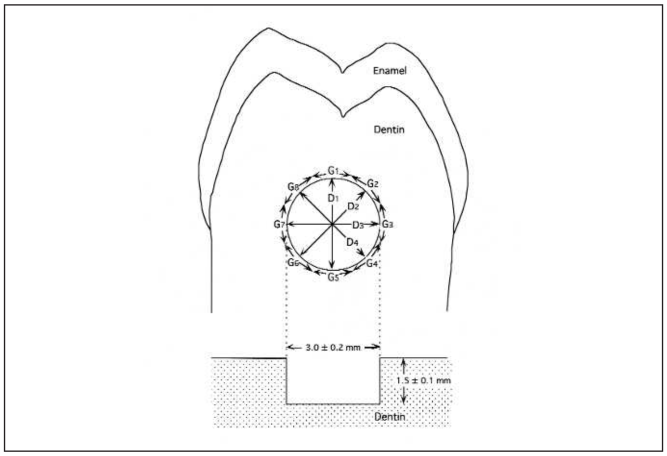


Figure 4. *Illustration of procedure for measuring of contraction gap.*

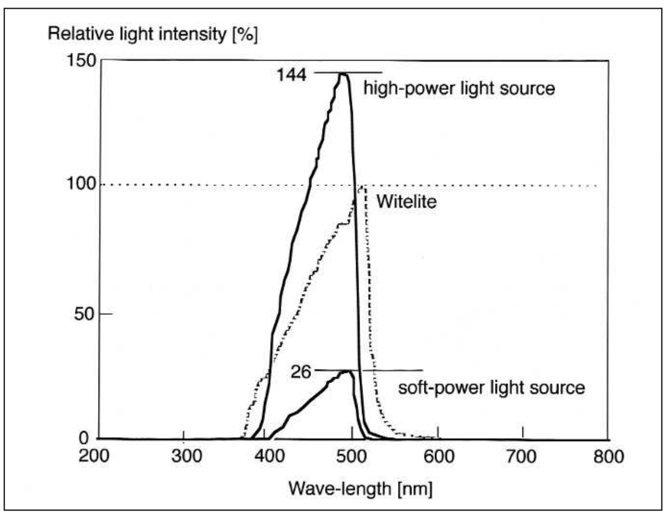


Figure 5. *Spectroscopic distribution of the soft and high-power light sources of the Elipar Highlight and the Witelite.*

## RESULTS

Figure 5 shows the spectroscopic distribution of soft-power and high-power light sources of Elipar Highlight and Witelite conventional halogen light sources. The soft and high-power of the tested lamp units exhibited 26% and 144% light intensity, respectively, compared to Witelite. Table 7 shows light intensities of the three light sources measured by commercially available light meters. The light intensities measured with the Apollo Meter were slightly lower than those measured with the Cure Rite meter. The curing depths of the four tested resin composites are listed in Tables 8 and 9. With the soft-power light source, a three-second exposure did not polymerize the resin composite paste. In addition, curing depth of the resin composite was not more than 3 mm with 10 seconds irradiation of the soft-power light (Table 8). When the resin composite was exposed to high-power light, the depth of cure was not less than 2 mm with three seconds of irradiation, and the entire 8 mm high cylindrical resin composite paste was polymerized with 20 seconds irradiation for all composite materials (Table 9). The wall-to-wall polymerization contraction gap formation of Estelite, APX and Silux

Table 6: *Irradiation Time and Curing Depth of Resin Composites Recommended by the Manufacturer*

| Resin Composite/Shade | Irradiation Time in Contraction Gap Study | Irradiation Time Recommended for Clinical Use | Irradiation Time | | |
|---|---|---|---|---|---|
| | | | 20 seconds | 30 seconds | 40 seconds |
| Clearfil APX/A3 | 40 seconds | no data* | 2.0 | 2.5* | 3.0* |
| Estelite /U (A3) | 40 seconds | no data** | 3.3** | 3.7** | 3.9** |
| Silux Plus /U | 40 seconds | 40 seconds*** | no data | 2.0*** | no data |
| Z-100 /A3 | 40 seconds | 40 seconds*** | no data | no data | 2.5*** |

* reported by Kuraray (mm)
** reported by Tokuyama
*** reported by 3M Dental Products

Plus was completely prevented in cavities treated with the experimental dentin bonding system regardless of the irradiation mode (Table 10). Complete marginal integrity could not be obtained by pretreatment of the commercial dentin bonding system regardless of the combination of resin composite and irradiation mode (Table 11). The Kruskal-Wallis test revealed a significant difference between the contraction gap of Z-100 and that of the other three resin composites ($p<0.05$), and the Mann-Whitney test revealed no significant difference in gap width between irradiation methods ($p>0.05$).

## DISCUSSION

A relationship between the rate of polymerization and cavity adaptation of light cured resin composite has been suggested. It is easily speculated that a faster polymerization causes poorer marginal integrity of resin composite restorations. Soft-start irradiation was introduced to reduce the initial contraction stress and prevent the separation of resin composite paste from the cavity wall during polymerization. Subsequently, soft-power irradiation was designed to be followed by high-power irradiation to ensure a high degree of polymerization of resin composite. However, as demonstrated in this study, the irradiation mode did not significantly influence the marginal integrity of resin composite restorations. In this study, contraction gap formation was prevented completely by using an experimental dentin bonding system regardless of the irradiation mode of the halogen lamp unit with the exception of Z-100. The adaptation of resin composite was determined by the combined efficacy of the dentin conditioner, primer and dentin bonding agent. The primary requirement for the dentin bonding system must be to prevent contraction gap formation. The authors previously reported that EDTA conditioning, priming with a glyceryl mono-methacrylate solution and a commercial dentin bonding agent containing functional monomers such as 10-metharyloxydecyl dihydrogen phosphate (10-MDP), 4-methacryloxyethyl trimellitate anhydride (4-META) or tetrahydroxyethyl methacrylate pyrophosphate (TMEPP) were the optimum combination for producing a contraction gap-free dentin bonding system (Manabe & others, 1999). Efficacy of the dentin bonding system and polymerization performance of resin composite play an important role in marginal integrity. Even when the cavity was pretreated with a dentin bonding system, a gap was still observed when shrinkage of composite in the cavity could not be compensated by flow composite from the free surface during polymerization. As demonstrated by Itoh, Yanagama & Wakumoto (1986) and Yukitani & others (1997), the flow of resin composite during polymerization is affected by the proportions of filler and resin. It has been speculated that the gap was possibly formed when the resin composite did not contain

Table 7: *Light Intensity of the Light Sources Measured with Commercially Available Light Meters*

| | Apollo Meter | Cure Rite |
|---|---|---|
| High-power light of Elipar Highlight | 600 | 650 |
| Soft-power light of Elipar Highlight | 100 | 140 |
| Witelite | 300 | 320 |

(mW/cm$^2$)

Table 8: *Curing Depths of Four Resin Composites in Cylindrical Teflon Mold Irradiated by the Soft-Power Light Source of Elipar Highlight*

| | Irradiation Time | | | |
|---|---|---|---|---|
| | 1 Second | 3 Seconds | 5 Seconds | 10 Seconds |
| APX | 0 | 0 | 1.30 ± 0.20 | 2.26 ± 0.17 |
| Estelite | 0 | 0 | 1.48 ± 0.22 | 2.40 ± 0.21 |
| Silux Plus | 0 | 0 | 1.64 ± 0.09 | 2.84 ± 0.11 |
| Z-100 | 0 | 0 | 1.92 ± 0.15 | 2.98 ± 0.18 |

N=5, Mean ± SD (mm)
Couple values joined by vertical lines are not significantly different analyzed by Tukey's multiple comparison test ($p>0.05$).

Table 9: *Curing Depths of Four Resin Composites in Cylindrical Teflon Mold Irradiated by High-Power Light Source of Elipar Highlight*

| | Irradiation Time | | | | |
|---|---|---|---|---|---|
| | 1 Second | 3 Seconds | 5 Seconds | 10 Seconds | 20 Seconds |
| APX | 0 | 2.56 ± 0.15 | 4.22 ± 0.15 | 6.06 ± 0.28 | >8 |
| Estelite | 0 | 2.52 ± 0.18 | 4.62 ± 0.11 | 6.22 ± 0.22 | >8 |
| Silux Plus | 0 | 2.96 ± 0.15 | 4.08 ± 0.19 | 6.46 ± 0.15 | >8 |
| Z-100 | 1.74 ± 0.19 | 4.42 ± 0.28 | 5.86 ± 0.15 | 7.68 ± 0.13 | >8 |

N=5, Mean ± SD (mm)
Couple values joined by vertical lines are not significantly different analyzed by Tukey's multiple comparison test ($p>0.05$).

Table 10: *Wall-to-Wall Contraction Gap with the Experimental Bonding System*

| | Irradiation Methods | | | |
|---|---|---|---|---|
| | High-Power Start | | Soft-Start | |
| Estelite | 0 | (10) | 0 | (10) |
| APX | 0 | (10) | 0 | (10) |
| Silux Plus | 0 | (10) | 0 | (10) |
| Z-100 | 0.287 ± 0.123 | ( 0) | 0.220 ± 0.056 | ( 0) |

N=10, Mean ± SD (number of gap-free specimens out of 10)
Couple values joined by vertical or horizontal lines are not significantly different analyzed by Mann-Whitney test ($p$>0.05).

Table 11: *Wall-to-Wall Contraction Gap with the Mega Bond System*

| | Irradiation Methods | | | |
|---|---|---|---|---|
| | High-Power Start | | Soft-Start | |
| Estelite | 0.010 ± 0.019 | (7) | 0.003 ± 0.010 | (9) |
| APX | 0.013 ± 0.021 | (7) | 0.002 ± 0.006 | (9) |
| Silux Plus | 0.027 ± 0.040 | (6) | 0.001 ± 0.002 | (9) |
| Z-100 | 0.071 ± 0.070 | (3) | 0.127 ± 0.104 | (2) |

N=10, Mean ± SD (number of gap-free specimens out of 10)
Couple values joined by vertical or horizontal lines are not significantly different analyzed by Mann-Whitney test ($p$>0.05).

the optimum filler content to compensate for the quantity of polymerization contraction. Furthermore, cavity adaptation of the resin composite might have deteriorated due to a high content of polymerization initiator as suggested by Asmussen (1975).

The poor marginal adaptation of the resin composite tested (Z-100) might be caused by its rapid polymerization rate because the curing depth of Z-100 was significantly greater than that of the other three resin composites tested. The rate of polymerization might be determined by the content of the polymerization initiator or the translucency of the resin composite. The chemical or physical property of Z-100 requires some improvement to reduce polymerization velocity.

## CONCLUSIONS

Marginal adaptation of a resin composite is influenced by the efficacy of the dentin bonding systems employed and polymerization performance of the resin composite rather than the irradiation mode of the light source. From a clinical point of view, however, rapid polymerization of the composite is desirable because the opportunity for contamination by saliva or blood can be minimized. From the results of this study, use of a high-power start mode halogen lamp or a high-power xenon lamp can be recommended if the cavity is pretreated with an effective dentin bonding system.

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# Adherence of Plaque Components to Different Restorative Materials

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### Clinical Relevance

New types of ceramics exhibited the least amount of bacterial and glucan adhesion compared to amalgam, resin composite and casting alloy irrespective of surface finishings.


## SUMMARY

**This study compared the amount of artificial plaque synthesized** *in vitro* **by** *Streptococcus sobrinus* **on various dental materials using radioisotopes. In particular, plaque-retaining capacities of new types of ceramics were the focus of this study.**

**Specimens were fabricated from the following materials (one amalgam alloy [Spherical-D], one casting gold alloy [Casting Gold TYPE I], one resin composite [Herculite XR] and three ceramics [Vita Celay Blanks, IPS Empress and Dicor MGC]). The amount of bacteria and glucans adhered on the specimens was measured after incubation for 24 hours at 37°C with radio-labeled cariogenic bacteria and sucrose. This adhesion test was performed using two different surfaces with 600-grit roughness and clinical smoothness. Irrespective of the surface roughness, the least amount of plaque adhered to the ceramics. However, in the case of the resin composite and amalgam, the amount of bacteria and glucan adhesion decreased dramatically by polishing, though there were no statistically different changes in the amount of bacteria and glucans that adhered to the ceramics even after polishing. In general, the amount of adhered bacteria showed almost the same tendency as that of glucans. Although no statistical differences in the amount of bacteria and glucan adhesion were detected among the three ceramics investigated in this study, a lesser amount of bacteria and glucans adhered to them compared to the other materials.**


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## INTRODUCTION

Recently, the necessity for tooth-colored restorations has greatly increased, while application of metal-colored restorations such as amalgam and metal casting restorations has become unpopular from an aesthetics perspective. Although resin composite or glass ionomer restorations have often been used for these aesthetic restorations, recently, various new types of ceramics have been developed and introduced in clinical cases (Garber & Goldstein, 1994; Anusavice, 1996; Rosenblum & Schulman, 1997). Various processing methods such as sintering, casting and machining have been adopted for fabricating ceramic restorations. Although glass ceramics (Stenberg & Matsson, 1993; Malament & Socransky, 1999) and other new types of ceramics (Tidehag & Gunne, 1995; Fradeani, Aquilano

& Bassein, 1997) have been used in dentistry for more than a decade, little is still known about their biological properties, such as plaque retention.

While it has already been reported that plaque has less of a tendency to accumulate on porcelains compared to other dental materials such as resin composites or amalgams (Adamczyk & Spiechowicz, 1990; Olsson, van der Heijde & Holmberg, 1992; Harn & others, 1993), when porcelain is insufficiently polished, the unpolished surface can grind the opposing tooth and make it rougher by wear (Seghi, Rosenstiel & Bauer, 1991; Ramp & others, 1997). Because it is well known that plaque has less of a tendency to accumulate on porcelain surfaces due to the smoothness (Adamczyk & Spiechowicz, 1990; Olsson, van der Heijde & Holmberg, 1992; Harn & others, 1993), surface roughness is still considered a very important factor that determines the amount of plaque accumulation (Quirynen & others, 1993; Quirynen & Bollen, 1995). Therefore, initially, all restorative materials were polished to the same surface roughness (Ra), then plaque adhesion was quantitatively measured using radioisotope labeled bacteria and sucrose. In this study, artificially synthesized plaque composed of bacteria and glucans is hypothesized to simulate actual dental plaque in a mouth. Then, these restoratives were polished by the respective clinically recommended methods and the amount of bacteria and glucans adhered was similarly measured. Finally, the amount of plaque that adhered to the two above-mentioned surfaces among the conventional porcelain and new types of ceramics were compared to understand the biological properties of the new types of ceramics.

## METHODS AND MATERIALS

### Preparation of Specimens

Table 1 shows the six restorative materials used in this study. Six discs of each material (9 mm diameter, 1 mm thick) were fabricated according to their manufacturer's instructions and stored in distilled water at 37°C for 72 hours. They were finished with 600-grit emery paper (R finishing), then half of the specimens were processed by the respective clinically recommended polishing methods (S finishing). The ceramic discs were polished with a diamond paste (Dia-Glaze, Renfert GmbH, Helzingen, Germany). The amalgam and casting gold discs were polished with silicon points, and those with the resin composite were polished with a Soflex disc systems (3M Dental Products Division, St Paul, MN 55144), respectively.

Table 1: *Restorative Materials Used in This Study*

| Products | Manufacturers | Characteristics |
|---|---|---|
| *Ceramics* | | |
| Vita Celay Blanks | Vita Zahanfabrik, Bad Sackingen, Germany | porcelain |
| IPC Empress | Ivoclar, Schaan, Liechtenstein | porcelain |
| Dicor MGC | Dentsply, Milford, DE, 19963 | glass ceramicsm |
| *Amalgam* | | |
| Sherical-D | Shofu, Inc, Kyoto, Japan | high-copper dispersed alloy |
| *Casting Gold* | | |
| Casting Gold TYPE I | Ishifuku, Tokyo, Japan | Type I gold alloy |
| *Resin Composite* | | |
| Herculite XR | Kerr, Romulus, MI, 48174 | hybrid type |

### Measurement of Surface Roughness (Ra)

The surface roughness (Ra) of the respective discs was measured with a profilometer (SE-40C, Kosaka Lab, Tokyo, Japan). Ra is the arithmetic mean of the departures of the roughness profile from the profile centerline. The Ra measurement was repeated three times.

### Radio-Labeling of Bacteria by [$^3$H] -Thymidine

*Streptococcus sobrinus* B13 was obtained from S Edwardsson (University of Lund, Malmö, Sweden) and stored in our laboratory until use at -80°C. The bacterium was inoculated into 150 ml of Brain Heart Infusion (BHI, Difco Lab, Detroit, MI 48232) broth including 0.5 mCi of (6-[$^3$H]-methyl)-thymidine (2.0 Ci/mmol, Amersham, LC Buckinghamshire, UK) and cultured at 37°C for 18 hours. The cells were collected by centrifugation at 1,500 x g for 15 minutes with 0.05 M phosphate buffer (pH 6.0; PBS). The washing procedure was repeated two more times, then, cells were suspended in PBS at a concentration of $10^7$ CFU/ml. These suspensions were ultrasonicated for 15 seconds in an ultrasonifer (model UP150P, Tomy, Tokyo, Japan) to eliminate bacterial chains. Then, cells were washed once in PBS to remove any radio-labeled components.

Radioactive hot sucrose solution was prepared by mixing 50 µl of [$^{14}$C]-sucrose (U) (602 mCi/mmoL, New England Nuclear, Boston, MA 02118) and 950 µl of distilled water.

### Adhesion Test of Bacteria and Glucans to Restoratives

The adhesion test was initiated by inoculating 100 µl of washed [$^3$H]-thymidine labeled bacterial cell suspension into 9.8 ml of BHI broth including 3% sucrose and 100 µl of [$^{14}$C]-labeled hot sucrose. Immediately after bacterial inoculation, the respective restorative discs were suspended with orthodontic wires (0.9 mm diameter) and agitated at 0.5 Hz in a shaking bath adjusted to 37°C.

After 24 hours of incubation, the specimens were removed from test vials, then immediately washed by PBS three times to remove non-adhered bacteria and glucans. Next, radioactivity of the specimens was determined by a liquid scintillation method using a liquid scintillation counter (model LSC-673, Aloka, Tokyo, Japan) after freeze-drying for

48 hours. The values obtained were defined as indices of the total number of bacteria and glucans adhered to the respective discs.

**Statistical Analysis**

One-way ANOVA tests for the amount of bacteria and glucan adhesion on the restorative materials were carried out for the two surface finishings (R and S). Then, Scheffe's method of multiple comparison was used to analyze significant differences among the respective materials.

## RESULTS

Table 2 revealed surface roughness (Ra) of the respective materials after the two surface finishings. Rough surfaces (finishing R) obtained by 600-grit abrasive paper showed around 0.24 as the Ra value, and the clinically smooth surfaces (finishing S) exhibited significantly smaller values between 0.08 and 0.14.

The amount of bacteria and glucans that adhered to the respective restorative materials was expressed in Table 3 and Table 4, respectively. When the materials were finished by 600-grit abrasive paper (finishing R), the greatest amount of bacteria and glucans were adhered to the amalgam, followed by the resin composite, then the casting gold. However, when clinically-accepted finishing methods were applied to the respective materials (finishing S), the amount of bacteria and glucan adhesion on amalgam and resin composite decreased significantly to less than one-tenth of that on the rough surface after 24 hours incubation.

Concerning plaque adhesion to the ceramics, there were no statistical differences in the amount of bacteria and glucans that adhered among the three ceramics, though Celay porcelain had a tendency to exhibit a greater amount of bacteria and glucan adhesion in the case of the rough surfaces. In contrast, the casting gold always showed the greatest amount of bacteria and glucan adhesion when the finishing surface was smooth.

Table 2: *Surface Roughness Values of Various Restoratives Obtained by Two Finishing Methods*

| Material | Surface Roughness (Ra) | |
|---|---|---|
| Surface Finishing | Finishing R | Finishing S |
| Celay | 0.25 (0.07)# | 0.12 (0.02) |
| IPS Empress | 0.24 (0.08) | 0.09 (0.02) |
| Dico MGC | 0.25 (0.09) | 0.11 (0.03) |
| Sherical-D | 0.25 (0.06) | 0.14 (0.01) |
| Casting Gold Type II | 0.23 (0.06) | 0.09 (0.01) |
| Herculite XR | 0.24 (0.05) | 0.08 (0.01) |

# Values in the parentheses represent the standard deviations.

Table 3: *Amount of [$^3$H]-thymidine Labeled Bacteria Adhered on the Respective Restoratives*

| Material | Amount of Bacteria Adhered (mean ± sd; dpm) | | | |
|---|---|---|---|---|
| Surface finishing | Finishing R | | Finishing S | |
| Dicor MGC | 3712.9 | (1463.9) #(a)§ | 2860.3 | (655.4) (c) |
| IPS Empress | 4731.3 | (148.9) (a) | 2767.2 | (380.9) (c) |
| Celay | 9988.2 | (2032.6) (a) | 2984.1 | (148.4) (c) |
| Casting Gold Type II | 25020.0 | (10742.9) (a,b) | 13300.9 | (4388.8) (d) |
| Herculite XR | 28270.6 | (20042.3) (a,b) | 2455.6 | (450.5) (c) |
| Sherical-D | 48373.6 | (14698.3) (b) | 4163.2 | (1057.0) (c) |

# Values in the parentheses represent the standard deviations.
§ Groups denoted by the same letter in parentheses represent no significant difference ($p$<0.05).

Table 4: *Amount of [$_{14}$C]-glucose Labeled Glucan Adhered on the Respective Restoratives*

| Material | Amount of Glucan Adhered (mean ± sd; dpm) | | | |
|---|---|---|---|---|
| Surface Finishing | Finishing R | | Finishing S | |
| IPS Empress | 917.3 | (66.5) # (a)§ | 479.8 | (163.5) (c) |
| Dicor MGC | 1034.2 | (373.1) (a) | 369.6 | (259.7) (c) |
| Celay | 1762.2 | (433.6) (a) | 552.1 | (158.2) (c) |
| Casting Gold Type II | 4364.2 | (1934.0) (a,b) | 2376.0 | (756.3) (d) |
| Herculite XR | 5085.3 | (3623.2) (a,b) | 734.4 | (348.6) (c) |
| Sherical-D | 8509.9 | (2765.1) (b) | 944.3 | (127.0) (c) |

# Values in the parentheses represent standard deviations.
§ Groups denoted by the same letter in parentheses represent no significant difference ($p$<0.05).

## DISCUSSION

As dental plaque accumulated on the restorations influences neighboring teeth and periodontal tissue, an increase in bacterial or plaque accumulation often induces dental caries or periodontitis. Thus, in addition to mechanical properties, plaque-retaining capacity would also be one of the most important characteristics for longevity of restorations and teeth. The amount of plaque that accumulated on various surfaces has been investigated in conjunction with various factors such as surface roughness (Quirynen & others, 1993; Quirynen & Bollen, 1995), electrical property (zeta potential) (Satou & others, 1988), hydrophobicity (Olsson & others, 1992) and surface free energy (van Dijken & Ruyter, 1987; Quirynen & others, 1989; Quirynen & others, 1993). Of these factors, surface roughness would play the most important role for initial plaque adhesion on dental materials. In this study, when initially removing a factor of surface roughness, all the specimen surfaces were polished to almost the same roughness. Thus, the effect of the materials *per se* on plaque adhesion could be judged from the results of finishing R in this experiment. However, as polishing or finishing methods differ clinically among the restorative materials, clinically recommended polishing methods were adopted as the second finishing method (finishing S). Therefore, the influences of materials *per se* and surface roughness on the bacteria and glucan adhesion on various dental materials were evaluated from both the finishing methods of R and S.

A number of studies have also investigated the rate or amount of plaque accumulation on various materials (Wise & Dykema, 1975; Ørstavik, Arneberg & Valderhaug, 1981; Dummer & Harrison, 1982; Adamczyk & Spiechowicz, 1990; Svanberg, Mjör & Ørstavik, 1990; Siegrist & others, 1991; Harn & others, 1993). These studies have reported that ceramics, including porcelain, showed the least amount of plaque adhesion, irrespective of surface treatments. On the contrary, metal restorations have often been reported to induce the greatest amount of plaque accumulation compared to other materials. The results of this study confirmed that bacteria and glucans adhered most to amalgam and resin composite, followed by casting gold, then ceramics. Although the results of this study were often consistent with those of previous studies, some dental materials such as amalgam or resin composites showed different results, depending on the surface roughness.

The reason why a strain of *Streptococcus sobrinus* was selected as the bacterium used in this study is that this bacterium is cariogenic due to its ability to synthesize copious adhesive glucans. Adding sucrose to the growth medium favors the plaque forming potential of this bacterium. With the help of these sticky glucans, the bacteria can adhere even to a smooth surface such as enamel or restoration (Gibbons & van Houte, 1973). Adhesion of bacteria at an early stage is usually explained by physical phenomena induced by the van der Waals force and electrostatic force (Quirynen & others, 1993). Then, once bacteria adhere or stagnate, they get firmly fixed on some irregularities or microcracks of the surfaces by species-specific various adhesive agents (Quirynen & others, 1993). In fact, since marginal gaps of restorations may frequently generate these irregularities and promote plaque accumulation, the areas may be more indicative of potential disease initiation such as recurrent caries.

Plaque was divided into two main components: bacterial cells and synthesizing glucans. As the actual amount of plaque would be a total sum of adhered bacteria and its synthesizing polysaccharides (glucan), it would be meaningful to quantitatively measure the amount of adhesion for these two components. A focus of this study was to investigate bacteria and glucan adhesion on recently developed ceramics. Because this test method used radio-labeled bacteria and sucrose, the plaque-retaining capacity was precisely measured comparatively. However, though a conventional porcelain (Celay) showed a tendency of more plaque adhesion compared to the other new ceramics, the differences of bacteria and glucan adhesion among the three ceramics were not statistically significant. Although plaque adhesion on the newly-developed ceramics has not been sufficiently investigated until now, there is a report that showed that glass ceramics such as Dicor had less plaque retaining capacity compared to the other ceramics (Savitt & others, 1987). Celay is a feldspathic porcelain and the other ceramics, IPS Empress is a leucite-enriched porcelain (Anusavice, 1996). It has been reported that these are composed of various sizes of crystals such as quartz or leucite (Anusavice, 1996). The size of the crystal might influence the surface roughness and amount of plaque accumulation. When these porcelains are polished, microcracks or micropores are easily produced by rotary cutting devices between the crystal and the matrix. These micro defects might be niches for bacterial stagnation or retention. On the other hand, a glass-ceramic (Dicor-MGC) includes anisotropic mica crystals and is easily cleaved (Anusavice, 1996). This crystalline alignment is uni-directional, resulting in the production of fewer surface irregularities with mechanical polishing. The differences in the amount of irregularities on the surfaces might explain those of plaque adhesion demonstrated among the three ceramics.

## CONCLUSIONS

1. Regarding bacterial and glucan adhesion, both adhered the most to amalgam, followed by resin composite, casting gold restoration and finally, the least on ceramics (600-grit abraded surfaces; finishing R).
2. However, when the surfaces were polished by the respective clinically accepted methods (finishing S), the order of the amount of bacteria and glucans adhered changed to casting gold > amalgam > ceramics > resin composite (bacteria); casting gold > amalgam > resin composite > ceramics (glucans).
3. Although there were statistical differences ($p<0.05$) between the three ceramics and the other three materials, no statistical differences were detected among the three ceramics in terms of the amount of bacteria and glucan adhesion.
4. The adhesion test using radiolabeled bacteria and sucroses exhibited that the influences of material per se and the surface roughness on plaque adhesion on various materials were different.

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# Effectiveness of Surface Protection of Resin Modified Glass Ionomer Cements Evaluated Spectrophotometrically

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### Clinical Relevance

It is necessary to use surface protectors over resin-modified glass ionomer cement restorations; all tested agents showed effective protection.


## SUMMARY

**The effectiveness of four surface protectors for resin-modified glass ionomer cements was evaluated by spectrophotometrically determining dye uptake. Ninety specimens, 3.0 mm in diameter and 1.0 mm in height, were made with Photac-Fil, Fuji II LC and Vitremer and divided into six groups for each material. Positive and negative controls were not protected while experimental specimens were protected with proprietary glaze, nail varnish, flowable resin and glaze. The discs were immersed in 0.1% methylene blue solution for 10 minutes after mixing, except for those negative control specimens that were immersed in deionized-water. After 24 hours, the specimens were washed and the protectors trimmed with Sof-Lex discs. The specimens were then removed from the matrixes and individually placed in 1.5 mL of 65% nitric acid for five hours. The absorbance was determined spectrophotometrically at 590 nm. Dye uptake was expressed in µg dye/specimen. The data were analyzed by two-way ANOVA and Tukey-Kramer tests. All surface protectors tested were effective. For Fuji II LC and Vitremer no differences were observed among tested protections. For Photac-Fil, nail varnish showed better performance than the proprietary glaze.**


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## INTRODUCTION

Conventional glass ionomer cements (GIC) set by an acid-base reaction between the ion-leachable glass and the polyalkenoic acid. Water plays an important role in this reaction and in the cement structure (Wilson & McLean, 1988). During early setting stages it is essential to protect the cement surface to avoid water loss or gain and the consequences of either (Mount, 1981; McLean, 1992). If water is lost due to desication, the reactions may stop and surface crazing may occur (Wilson & Mc Lean, 1988; McLean, 1992). On the other hand, too much water can wash out the calcium and aluminum ions and the cement will lose its translucency (McLean, 1992).

The light-activated bonding resins have been cited as effective agents in limiting water movement across the conventional GIC surface (Earl, Mount & Hume, 1989; Hotta, Hirukawa & Yamamoto, 1992). Clear nail varnishes have also shown effective protection for these materials (Serra & others, 1994; Carneiro & others, 1995; Valera & others, 1997).

Changes have been made in GICs by adding resin components to the conventional materials to improve some characteristics. Resin-modified GICs (RM GICs) have two mechanisms of setting: the acid-base setting reaction and a polymerization reaction (Wilson, 1990; Craig, 1997). This latter reaction can be a self-cure of the resin phase and/or it can occur by light activation. Resin-modified GICs were developed to improve the mechanical properties of conventional materials (Mathis & Ferracane, 1989; Mitra, 1991; Uno, Finger & Fritz, 1996) and to overcome early moisture sensitivity (Mathis & Ferracane, 1989; Wilson, 1990).

However, studies have shown that there is a detriment in the esthetic properties of non-protected resin-modified GIC restorations after two (Beltrão & others, 1996) and three years (van Dijken, 1996). This may be attributed to the lack of surface protection against moisture contamination (van Dijken, 1996). Thus, it is important to compare surface agents and verify whether they can protect resin-modified GIC against the uptake of fluids. Ribeiro & others (1999) tested some surface protectors and showed the best to be Heliobond (Ivoclar/Vivadent, Schaan, Liechtenstein) light-activated bonding resin. Some other protective materials were indicated as surface protectors for RM GIC such as flowable resin (Albers, 1998) and Taub glaze (George Taub Products & Fusion Co Inc, Jersey City, NJ 07307).

This study spectrophotometrically evaluated the effectiveness of these surface agents applied on restorative resin-modified glass ionomer cements immediately after setting.

## METHODS AND MATERIALS

Three resin-modified restorative glass ionomer cements were used in this study (Table 1).

The materials were manipulated according to the manufacturers' directions. Photac-Fil, the encapsulated material, was mechanically mixed in a proprietary capsule mixer (Capmix, ESPE, Dental-Medizin GmbH & Co KG, Seefeld, Germany, D 82229) for 15 seconds. Fuji II LC and Vitremer were prepared using the powder-to-liquid ratio shown in Table 1 and mixed for 25 and 45 seconds, respectively. The glass ionomers were injected into plastic rings (3.0 mm in diameter and 1.0 mm height). The specimens made with Photac-Fil and Vitremer were light cured for 40 seconds, and those made with Fuji II LC were light cured for 20 seconds with an activating light (XL 1500, 3M Dental Products, St Paul, MN 55144). Ten minutes after the start of mixing, the specimens were protected with petroleum jelly. Cement excess was trimmed off and the specimens protected with one of the surface protectors, except for the two control groups.

Four surface treatments were evaluated (Table 2). The nail varnish used is essentially composed of camphor, nitrocellulose, sulfonamide and toluene. The "glaze" (Taub glaze) is a fast setting liquid acrylic resin indicated over resin-modified glass ionomer cements. The flowable resin is essentially composed by ethoxylato Bis-GMA (bisphenol–glycidyl methacrylate), TEG DMA (triethylene glycol-glycidyl methacrylate), barium glass, silica and $TiO_2$. The proprietary glazes are surface coatings indicated by the manufacturers of the resin-modified glass ionomer materials. The components of Fuji Coat LC are aliphatic dimethacrylate, multifunctional urethane dimethacrylate, methyl methacrylate and tertiary amine. Finishing Gloss pres-

Table 1: *The Resin-Modified Restorative Glass Ionomer Cements Used*

| Material | Manufacturer | Power/Liquid Ratio | Batch # | |
|---|---|---|---|---|
| Fuji II LC | GC America, Chicago, IL 60658 | 3.0/1.0 (g/g) | powder: 111261 | liquid: 271161 |
| Photac-Fil | ESPE Premier, Norristown, PA 19404 | encapsulated | 06102 | |
| Vitremer | 3M Dental Products, St Paul, MN 55144 | 2.5/1.0 (g/g) | powder: 19971120 | liquid: 19971120 |

Table 2: *The Surface Treatments Evaluated*

| Group | Material | Manufacturer | Batch # |
|---|---|---|---|
| Positive control | No protection | _____ | _____ |
| Negative control | No protection | _____ | _____ |
| Nail varnish | Colorama | CEIL - Com Exp Ltda São Paulo SP 66309 | L 8050362 |
| Flowable resin | Flow it! | Jeneric Pentron Inc, Wallingford, CT 06492 | 740922 |
| Glaze | Taub Glaze | George Taub Products & Fusion Co Inc, Jersey City, NJ 07307 | IL 9702 |
| Proprietary glaze | Fuji Coat LC<br>Ketac Glaze<br>Finishing Gloss | GC<br>ESPE<br>3M | 130661<br>10026015<br>19971120 |

ents Bis-GMA and TEG DMA in its composition. The composition of Ketac Glaze is aliphatic bisacrylate, amin diol methacrylate, camphor quinone, benzil dimethyl ketale, methoxy phenole and butyl hydroxy toluene. Five specimens of each material were prepared for each treatment and for the positive and negative control groups. Surface treatments were applied with a brush to both exposed surfaces of each specimen except for flowable resin that was applied with a plastic spatula and light cured for 40 seconds at each exposed surface. Nail varnishes Colorama and Taub glaze were allowed to dry for two minutes according to Valera & others (1997). Ketac Glaze and Fuji Coat LC were light cured for 10 seconds and Finishing Gloss for 20 seconds at each exposed surface.

After surface treatment, experimental group specimens were immersed in 0.1% methylene blue solution at 37°C and negative control specimens were immersed in deionized water. After 24 hours specimens were rinsed with deionized water and protective materials were trimmed off with medium SofLex discs (3M) for five seconds. The method used to quantify the effectiveness of surface protection was adapted from that of Douglas & Zakariasen (1981). The specimens were removed from the plastic rings and immersed separately into tubes containing 1.5 mL of 65% nitric acid for five hours. Both the dye concentration of methylene blue and the time necessary to remove it from the specimens were obtained from a pilot study. The absorbance was determined by a spectrophotometer (Amersham Pharmacia Biotech, Uppsala, Sweden 75184), and the use of a calibration curve. The effectiveness of the surface treatments was recorded as µg dye per specimen with lower values corresponding to better protection.

The data were submitted to two-way ANOVA at the 5% level of significance and the Tukey-Kramer test for multiple comparisons.

## RESULTS

The results are shown in Table 3.

The positive control group allowed the greatest dye penetration ($p<0.05$). The negative control group showed no dye.

No statistically significant differences were found for Fuji II LC and Vitremer among the tested protective materials. For Photac-Fil, there was a statistically significant difference between the nail varnish and its proprietary glaze ($p<0.05$).

## DISCUSSION

The non-protected resin-modified GIC specimens immersed in methylene blue (positive control) presented a statistically significant higher dye uptake than the other groups ($p<0.05$). This suggests that these materials can take up oral fluids. Studies have shown that water sorption of resin-modified GIC is dependent on the hydroxyethylmethacrylate (HEMA) content (Yap, 1996; Kanchanavasita, Anstice & Pearson, 1997). HEMA is hydrophilic in nature and materials with a higher HEMA content consequently have higher water sorption.

All the tested protective materials were effective in preventing the uptake of dye. Except for nail varnish that gave better results than proprietary glaze for Photac-Fil, there were no significant differences among the protective materials for Vitremer and Fuji II LC. The significant difference observed between the nail varnish and proprietary glaze for Photac-Fil may be due to the difficulty found in spreading this material. The authors observed an irregular distribution of Ketac Glaze on specimen surfaces. Using petroleum jelly to cover glass ionomer cements has the advantage of protecting the surface of the material immediately after matrix removal. The association between petroleum jelly and nail varnish is also advantageous when compared to proprietary glazes and surface protective resins in terms of cost/benefit according to Valera & others (1997). However, all the excess petroleum jelly should be carefully removed before painting the nail varnish, proprietary glazes or flowable resins; otherwise, this association of materials will not adequately protect the glass ionomer cements. This is not as critical for fluid materials such as varnishes, but for viscous materials, it can exert a negative effect.

The mean values for the negative control groups (0.00 ± 0.00) show that there was no dye in the glass ionomer cements tested. Consequently, the values of the experimental groups represent only the methylene blue that was taken up.

The results of this study are in agreement with that of Ribeiro & others (1999) regarding the need for surface protection because all tested protective materials were

Table 3: *Mean and SD of the Dye Penetration in Resin-Modified Glass Ionomer Cements (in µg/specimen, n=5)*

| Group / Material | Positive Control | Negative Control | Nail Varnish | Flowable Resin | Glaze | Proprietary Glaze |
|---|---|---|---|---|---|---|
| Photac-Fil | 39.53 ± 9.08 | 0.00 ± 0.00 | 0.00 ± 0.00 | 1.07 ± 0.15 | 3.08 ± 0.73 | 5.71 ± 1.49 |
| Fuji II LC | 15.56 ± 3.54 | 0.00 ± 0.00 | 0.37 ± 0.11 | 1.87 ± 0.44 | 1.19 ± 0.21 | 1.25 ± 0.31 |
| Vitremer | 11.40 ± 1.31 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.28 ± 0.08 | 0.54 ± 0.24 | 1.81 ± 0.03 |

effective in preventing dye penetration. However, there was disagreement in terms of the effectiveness of such materials. While nail varnish showed the same effectiveness as that observed with conventional GIC (Serra & others, 1994; Carneiro & others, 1995; Valera & others, 1997), Ribeiro & others (1999) observed the least protection with this material. Probably, the viscosity of the varnish used in this work differed from that used by Ribeiro & others (1999). Regarding Ketac Glaze, the results of Ribeiro & others (1999) also differed from what was observed in this work. The reasons may relate to the technique used because Ribeiro & others applied two coats of the proprietary glaze: before and after trimming, but the light activation for 20 seconds was performed only after trimming. In this study, the glaze was applied only once after removing the petroleum jelly and photocuring for 10 seconds according to the manufacturer's instructions. Due to the divergences of the results regarding Ketac Glaze, it is advisable not to use petroleum jelly with this protective material.

Protective surface agents have been indicated for conventional GICs in the initial setting stages to prevent early water loss or gain (Mount, 1981; Wilson & McLean, 1988). Water has an important role in the cement. It is responsible for transporting calcium and aluminum cations, which will react with the polyacid to form a polyacrylate matrix (Wilson & McLean, 1988). If water is lost due to desication, the reactions may stop and surface crazing may occur (Wilson & McLean, 1988; McLean, 1992). On the other hand, too much water can wash out the calcium and aluminum ions and the cement will lose its translucency (McLean, 1992). Although the need for protection of conventional GICs is well known, there is a controversy with respect to resin-modified ionomers. It is believed that the formation of an organic matrix protects them against early contamination by water (Wilson, 1990). However, Um & Oilo (1992) observed that increasing the time after the start of mixing before water immersion resulted in less solubility and setting changes of the RM GIC studied. Although the time effects before water immersion were less noticeable in the RM GIC, it was shown that these materials are also water sensitive in the early setting stages. The better results found by delaying water exposure after the start of mixing are probably due to the acid-base reaction which increases solidity and resistance to water degradation. In addition, van Dijken (1996) observed that non-protected Class III resin-modified GIC restorations showed the highest color change, surface degradation and roughness compared with the polyacid-modified resin composite and resin composite restorations after three years. Similar results found by Beltrão & others (1996) verified that while conventional Class III GIC restorations showed an improvement in esthetics, the non-protected Class III resin-modified GIC restorations showed color change after two years. The color change may be caused by contamination during the residual acid-base reaction (van Dijken, 1996). This reaction is slower in resin-modified GIC than in conventional materials (Craig, 1997). The rougher surface texture of resin-modified GICs observed in the laboratory after accelerated aging (Davis, Friedl & Powers, 1995) and clinically (van Dijken, 1996) also may affect the color. The rougher surface increases the scattering of incident light (Powers, Fan & Raptis, 1980). Moreover water sorption usually decreases color stability because water-soluble stains can penetrate the restoration (Albers, 1996).

A comparison of protected and non-protected restorations would be important to verify the real influence of the surface protection in the restoration performance. Clinical studies are also necessary to compare the performance of different protective agents over resin-modified GIC restorations. Tooth brushing and dietary habits can influence the retention of these agents and the results may be different from those in this laboratory study.

## CONCLUSIONS

The RM GICs need surface protection. All the protective materials tested were effective. Clinical studies are necessary to validate the results of this laboratory study.

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# Effect of Liners on Cusp Deflection and Gap Formation in Composite Restorations

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**Clinical Relevance**

Using a resin-modified glass ionomer liner beneath directly placed MOD resin composite restorations decreased the polymerization-induced cusp deflection.

**SUMMARY**

**This study measured deformation of cusps and gap formation associated with MOD resin composite restorations in maxillary premolars with and without the use of low elastic modulus liners. Low elastic modulus liners may reduce the deformation by absorbing polymerization shrinkage stress. Forty maxillary premolars were mounted in stone and slot MOD cavities were prepared. Teeth were randomized into four groups. In Group A, cavities were etched, Single Bond was applied and the cavities were restored with Z-100 composite. In Group B, the same was done except that a layer of flowable composite (Revolution) was place and cured after the bonding agent. In Group C, the same steps were followed as Group A but a layer of glass ionomer (Vitrebond) was placed and cured before the bonding agent. In Group D, a thin layer of composite was placed (after the bonding agent) as a base and cured and the cavities were filled. The distance between indexed cusp tips was measured before the restorations were finished and five minutes and 24 hours after the restorations were completed. The samples were then sectioned mesiodistally and epoxy resin replicas were made and prepared for SEM evaluation of gap formation. The mean contraction of the cusps in µm at 5 minutes and 24 hours, respectively, for each group was A) 47 and 30, B) 35 and 21, C) 23 and 8 and D) 40 and 28. Groups A and D resulted in the highest deformation, B was intermediate and C was the lowest. There was no statistically significant difference in gap formation between the groups.**

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## INTRODUCTION

A major disadvantage of posterior composite restorations is high polymerization shrinkage. *In vitro* measurements of polymerization shrinkage of resin composites range from 0.2% to 2% linear shrinkage (Hansen, 1982) and from 1.7% to 5.7% volumetric shrinkage (Bausch & others, 1982). Polymerization shrinkage of posterior composite restorations may induce mechanical stresses on the tooth structure via the bond to enamel and dentin. The magnitude of the polymerization stresses depends on the material's composition, stiffness and flow of the composite, rate of polymerization, the volume of the material to be polymerized and the geometry of the restoration (Carvalho & others, 1996). If the bond to tooth structure is strong enough, strain of tooth structure will occur. However, if the bond between the composite and the tooth structure is less than the force of polymerization shrinkage, a marginal failure and subsequent microleakage will occur (Davidson, de Gee & Feilzer 1984).

Several compensatory restorative techniques have been advocated to minimize the development of stresses at the margins and the risk of gap formation. According to Feilzer, de Gee & Davidson (1988), for compensation of the contraction and relief of stresses, the restorative material should flow in the direction of the cavity walls during the early setting. To some extent, the degree of stress development can be controlled by the cavity design (C-factor) (Feilzer, de Gee & Davidson, 1987). Generally, the less free, unbonded area there is in the cavity, the less the ability of the resin to flow, and therefore the greater will be the contraction stress at the bonded interfaces. Reduction of polymerization shrinkage can be achieved by reducing the mass of the restorative material with the use of a liner or base. Use of glass ionomer bases under resin composite restorations has reduced the stresses generated at the cavity walls during polymerization (Tolidis, Nobecourt & Randall, 1998; Davidson, 1994). Resilient lining cement or low elastic modulus materials have also been recommended because they are believed to absorb the volumetric changes. The low modulus materials can stretch or flow to allow stress relaxation (Moon, 1995).

This study measured the modifying effects of low elastic modulus liners on cusp deflection resulting from polymerization shrinkage of resin composite. The specific aims of this research were: 1) to compare the cusp deflection resulting from polymerization shrinkage of resin composite using different bases and liners and 2) to detect any gaps that might form at the interface between the liners/bases and the cavity floor. The specific liners/bases used in this study were bonding agent alone, light cured glass ionomer, flowable composite and a thin layer of composite was used as a control group.

## METHODS AND MATERIALS

Forty extracted maxillary premolars stored in 0.1% thymol were used. The teeth were examined under 2X magnification and determined to be caries free and without fractures or cracks. The roots of specimens were embedded in dental stone. The cementoenamel junctions were positioned 3 mm above the stone to prevent reinforcement of the crown by the stone. Following mounting, MOD slot cavities were prepared in the teeth using a high-speed handpiece and a #55 bur with water spray coolant. The preparations were centered between the facial and lingual cusps so as to preserve the maximum dentinal support for both cusps. The width of the cavities was 3.5 mm and the depth of the pulpal floor was 4 mm. The teeth in which pulp exposure occurred during the preparation were replaced. They were sorted into four categories according to size. The teeth were then randomly distributed into four groups of 10 teeth each.

### Cusp Deflection

In Group A, the cusp tips were leveled off and thin, diamond shaped aluminum foil was bonded to each cusp tip using Single Bond adhesive system (3M Dental Products Division, St Paul, MN, 55144 USA). The distance between the cusp tips (between the tips of the aluminum foil) was measured using a microscope with a micrometer stage. Following measurement, the cavities were acid etched using 35% phosphoric acid for 15 seconds. Then, the teeth were rinsed and gently air dried to remove excess water. A dentin bonding agent (Single Bond) was applied in two layers, then air dried gently and cured for 20 seconds using a visible curing light (Caulk Spectrum 800, Caulk Division, Dentsply International Inc, Milford, DE 19963 USA). Z100 resin composite, shade A3, (3M Dental Products; batch #247865A) was placed and cured in two equal increments. Each increment was cured for 40 seconds using the same curing light. The output of the light unit was measured with a curing radiometer between the subgroups to ensure a constant value of light intensity of 800 $mW/cm^2$. No matrix band was used, so that no tension was applied to the cusps. After five minutes, the distance between the cusp tips was again measured from the same points. The teeth were then placed in water and kept in a refrigerator at 4°C for 24 hours and the distance between the cusp tips was remeasured. The third measurement determined the degree of stress relaxation in the cusps. The teeth were then returned to the water prior to gap formation measurement.

The teeth in Group B were prepared and restored the same as Group A, except that a layer of flowable composite (Revolution, Kerr, Orange, CA 92867 USA) shade A3 was used as a base after the bonding agent was applied. Although the thickness of the base is more important, it was difficult to precisely measure the thickness everywhere. Thus, each tooth was weighed before and after the base was applied in order to keep the weight of the base constant (1 mg) between samples. Base thicknesses were estimated to be about 1 mm.

In Group C, the same procedures were followed as that for Group A, except that a layer of light cured glass ionomer (Vitrebond, 3M Dental Products) was applied and light cured for 30 seconds prior to applying the bonding agent. Each tooth was weighed before and after the base was placed so that the weight of the liner could be determined. The weight of the base was kept constant (1 mg) in all samples. In Groups B and C, the liners were applied to the entire pulpal floor.

In Group D, a thin increment of resin composite (Z-100) was applied to the pulpal floor and cured for 40 seconds as a liner after the bonding agent was applied as in Group A. The weight of this layer was the same as that of the glass ionomer and flowable composite liners used in Groups B and C (1 mg). The cavities were then filled with two layers of composite as in Group A. In all groups, the distance between cusp tips was measured three times: before the restoration, five minutes after curing and at 24 hours after curing.

**Gap Formation**

After the final cusp tip measurements were implemented, each tooth was sectioned mesiodistally into two halves using a low-speed diamond disk. One section was acid etched with 35% phosphoric acid for 10 seconds to remove the smear layer, rinsed with water for 20 seconds and briefly dried. Replica impressions were made of each section with a polyvinylsiloxane impression material (Extrude, light body, Kerr). The negative impressions were then replicated with a transmission electron microscope resin (epoxy resin) to obtain positive casts. The casts were gold coated and prepared for SEM. Each interface between the liner and pulpal floor was evaluated with an SEM at x250. Each sample was classified as: (0) perfect marginal integrity or (1) presence of a marginal gap as defined by Kemp-Scholte & Davidson (1990).

**Statistical Tests**

The means and standard deviations of the differences between the measurements at five minutes and the pre-restoration measurements were calculated. The means and standard deviations of the differences between the measurements at 24 hours and the pre-restoration measurements were also calculated. One-way ANOVA and Duncan's multiple range tests compared the groups at a significance level of $a<0.05$.The number of samples with gaps in each group was calculated and Kruskal-Wallis One-way ANOVA by ranks was used to compare the four groups, again at a significance level of $a<0.05$.

## RESULTS

The means and standard deviations of cuspal deflection at five minutes (differences between the intercuspal distance at five minutes and those before the restorations) are reported for each group in Table 1. Group C (the glass ionomer base) showed the least cuspal deflection. Meanwhile, Group A (no base) showed the highest cuspal deflection. The other two groups were in between.

Table 2 shows the means and standard deviations (in mm) of cuspal deflection at 24 hours for each group. Again, Group C showed the least and Group A the highest degree of cuspal deflection. The differences between the values in Tables 1 and 2 are presented in Table 3. These values represent the degree of cuspal relaxation that occurs because of hygroscopic expansion, elasticity of the tooth structures, gap formation or tooth fracture. Group A showed higher recovery than Group D. The other groups were not different.

One-way analysis of variance analyzed differences between the groups. At five minutes after curing of the composite (values in Table 1) analysis indicated a significant difference between groups ($a<0.05$). The results of the Duncan test showed that Group A (bonding agent alone) was different from the other three groups and gave the highest deflection. Group C (glass ionomer base) was different from the other three groups and gave the least degree of deflection. There was no statistical difference between Groups B (flowable composite) and D (resin composite base).

One-way analysis of variance again detected differences between the groups for cuspal deflection at 24 hours (values in Table 2). The Duncan test showed no statistical difference between Groups A (bonding agent) and D (resin composite base). Group C (glass ionomer base) was statistically different from the rest of the groups and it was the group with least deflection. Group B (flowable composite) was also statistically different from the other groups and better than Groups A and D, but worse than Group C.

The Duncan test for the difference in cuspal deflection between five minutes and 24 hours for the four groups (Table 3) showed that Groups A, B and C were statistically the same and Groups B, C and D were also statistically the same. Therefore, only Groups A and D were

Table 1: *Means and Standard Deviation (µm) of the Cusp Deflection at Five Minutes after Curing*

| Group | Mean ± SD (µm) | Range (µm) |
|---|---|---|
| Bonding agent alone (A) | 47 ± 8 a | 23 |
| Flowable composite base (B) | 35 ± 5 b | 17 |
| Glass ionomer base (C) | 23 ± 3 c | 10 |
| Composite base (D) | 40 ± 7 b | 23 |

*Homogeneous subsets are displayed.*

Table 2: *Means and Standard Deviations (µm) of Cusp Deflection at 24 Hours*

| Group | Mean ± SD(mm) | Range (µm) |
|---|---|---|
| Bonding agent alone (A) | 30 ± 6 a | 18 |
| Flowable composite base (B) | 21 ± 6 b | 21 |
| Glass ionomer base (C) | 8 ± 4 c | 15 |
| Composite base (D) | 28 ± 6 a | 20 |

*Homogenous subsets are displayed.*

Table 3: *Means and Standard Deviations (µm) of the Difference Between Cusp Deflection at 24 Hours and at Five Minutes (cusp relaxation)*

| Group | Mean±SD (µm) | Range (µm) |
|---|---|---|
| Bonding agent alone (A) | 17 ± 5 a | 14 |
| Flowable composite base (B) | 14 ± 4 a b | 11 |
| Glass ionomer base (C) | 16 ± 3 a b | 10 |
| Composite base (D) | 12 ± 3 b | 10 |

*Homogenous subsets are displayed.*

Table 4: *Number of the Samples with Gap Formation*

| Group | Count |
|---|---|
| Bonding agent alone (A) | 6/10 |
| Flowable composite base (B) | 6/10 |
| Glass ionomer base (C) | 8/10 |
| Composite base (D) | 7/10 |

statistically different for the amount of cusp relaxation. Group A had the highest absolute amount of relaxation, followed by Group C. Group D had the least amount of relaxation.

The number of samples with gap formation at the interface between the restoration and the dentin is summarized in Table 4. Groups A and B had six samples each with gap formation. Group C had eight samples, and Group D had seven samples with gap formation. The Kruskal-Wallis test showed no statistical difference between the groups for gap formation.

## DISCUSSION

Weakened cusps can move up to 15 µm in the first 15 minutes post cure using bulk-placed composite and dentin bonding agent (McCullock & Smith, 1986). They also showed that with incrementally packed resin composites, and the use of a glass ionomer base, cusp deflection was reduced to approximately 5 µm. The results of this study qualitatively agreed with their study except that our deflections are higher. This could be due to differences in variables such as composite material, size of the cavities and curing light intensity. The difference could also be due to higher bond strength to tooth structure achieved with current bonding agents. Polymerization stress may be transferred to the tooth structure through improved bonding. McCullock & Smith used self-cured glass ionomer, while the authors used resin-modified light-cured glass ionomer. The thickness of the base could also be a factor in the differing results. McCullock & Smith used the base to replace the thickness of dentin, while in this study, the authors used a thin layer of constant weight.

Causton, Miller & Sefton (1985) found inward cusp movement to be 2% over a period of a week. They also found that water adsorption had no effect on cusp movement up to one week post cure. The results of this study and others (Suliman, Boyer, & Lakes, 1993) showed that water adsorption reduces cusp deflection. This study showed that the degree of cusp relaxation was about one-third of the original deflection. This relaxation (recovery of the cusps) could result from either water adsorption or elastic relief of tooth structure or a combination of these effects.

The results of this study also agree with those of Rooklidge, Boyer & Bouschlicher (1999) who found that the use of a flowable composite liner reduces cusp deflection by almost one-third. The idea behind this is that flowable composite materials have low elastic modulus, therefore, they act like a cushion and absorb the stress that results from polymerization shrinkage. Feilzer & others (1988) also found the use of glass ionmer cement as a base under composite restorations reduces the polymerization contraction forces. According to their study, only 40% to 50% of shrinkage of glass ionomer cement had occurred during the first 10 minutes of curing. Therefore, flow of the material may still proceed during the stage in which the bond gained strength. Kemp-Scholte & Davidson (1990) demonstrated polymerization stress relief of 50% to 18% for a 5 mm sample of a chemically cured composite cured in contact with a thin layer of resin-modified glass ionomer liner. Tolidis & others (1998) found that the use of a resin-modified glass ionomer liner reduced volumetric polymerization contraction for the light cured composite material to approximately 61%. In this study, cusp deflection, measured five minutes after curing, was reduced approximately 50% by the use of resin-modified glass ionomer. After one day in water the total reduction in cusp deflection in Group C (where the resin-modified glass ionomer was used as a liner) was about 43% less than Group A, where only dentin bonding agent was used.

The flowable composite used in this study (Revolution, Kerr) had a modulus of elasticity of 7.7 GPa and volumetric polymerization shrinkage of 5.5 vol%. At the same time Z100 had a modulus of elasticity of 20.1 GPa and volumetric polymerization shrinkage of 2.3 vol% (Labella & others, 1999). The resin-modified glass ionomer (Vitrebond, 3M) had a modulus of elasticity of 1.1 GPa and a volumetric polymerization shrinkage of 2.3 vol% (Tam, McComb & Pulver, 1991). The volumetric polymerization shrinkage and the elastic modulus have opposite effects on the total stress on tooth structure and eventually on cusp deflection. High polymerization shrinkage could explain why the flowable composite, although it has low elastic modulus, was not as effective as the resin-modified glass ionomer in reducing cusp deflection.

Cusp deflection was slightly less when a thin layer of composite was used as a base (Group D) than when no base was placed (Group A). The use of a thin base of composite might reduce the C-factor for the remaining part of the restoration. Lutz, Krejci & Barbakow (1991) and others showed that incremental filling reduced stresses generated in the cavity walls due to polymerization shrinkage of the resin composite by reducing the volume of the composite. They stated that incremental filling technique may reduce the polymerization shrinkage stresses by lowering the C-factor to less than one because there is as much free surface as bonded surface for each increment. There was no statistical difference in cusp deflection between the two groups (A and D) at 24 hours.

Cusp deflection with the flowable composite liner (Group B) was not statistically different than the composite base (Group D) at five minutes. Although flowable composites have lower elastic modulus than the regular resin composite filling materials, they have higher polymerization shrinkage and therefore these two opposing factors might negate each other. At 24 hours there was a statistical difference in cusp deflection between the flowable composite group and both the composite base and the dentin-bonding agent (Group A). This might be attributed to higher hygroscopic expansion of the flowable composite due to its higher resin content.

The values of cusp relaxation ranged from 12 µm to 17 µm, which is in agreement with research done by Suliman & others (1993). The degree of relaxation was the same with all three liners. The only significant difference was that the composite liner resulted in less recovery than no liner. There is no clear reason for this finding. The authors hypothesize that recovery is due to hygroscopic expansion of the materials, which is similar for all of them.

Gap formation was measured in this study because the base material might reduce the polymerization shrinkage stresses by loss of bonding from the floor of the cavity and creating an undesirable gap. No differences were found among the groups in gap formation, therefore, this variable could not explain the variations in cusp deflection results.

Although there was no statistical difference between the groups in gap formation, the glass ionomer base group had the highest number of samples with gap formation. The fluidity of the glass ionomer is less than the dentin-bonding agent which had been used in the other groups before the base. The bonding agent was applied after the glass ionomer base had been placed. Bonding agents with greater fluidity result in more intimate contact with the dentin and fewer gaps or voids. The authors placed the bonding agent after the glass ionomer to simulate the clinical situation.

## CONCLUSIONS

This *in vitro* study showed that posterior composite restorations stress tooth structure, and this stress, with the presence of strong bonding between the restoration and the cavity walls, leads to deflection of the cusps. After five minutes, the maximum cusp deflection was 47 µm (when using only a bonding agent) and the minimum was 23 µm (with the use of glass ionomer as a base). The same trend remained for the 24 hour values. The maximum cusp deflection was 30 µm when using the bonding agent alone, while the minimum was 8 µm when using a resin-modified glass ionomer base.

The use of low elastic modulus liners reduced cusp deflection at five minutes after curing, but resin-modified glass ionomer was more effective in this regard than the flowable composite. This could be due to other variables such as the flow, polymerization shrinkage and degree of adhesive bonding of the materials.

Water immersion of the samples for 24 hours resulted in cusp relaxation that was between 12 µm and 17 µm. This relaxation was almost the same for all groups and did not result in complete recovery of the cusp deflection.

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## Clinical Survey

# Current Teaching of Cariology in North American Dental Schools

TD Clark • IA Mjör

### Clinical Relevance

Research in cariology has greatly improved our understanding of the disease dental caries and is providing new, more effective and conservative treatment alternatives. In this paper, the attention given this major field of study by North American Dental Schools was reviewed.


### SUMMARY

**All 65 dental schools in the United States and Canada were contacted to obtain information relevant to their cariology teaching effort, the caries management philosophy, the diagnostic threshold for surgical intervention and the non-surgical treatment alternatives implemented.**

**Forty-three schools (66%) responded to the request for information. Marked variations in the teaching of cariology and the implementation of modern diagnostic and treatment modalities were noted. The results indicate that with exceptions, efforts to increase curricular time and make organizational changes that would promote cariology as an important academic and clinical endeavor have fallen far short of predictions made more than 20 years ago for North America.**

**Many cariology programs in North American dental schools lack the detail and depth expected for this important area of clinical dentistry.**


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### INTRODUCTION

Over the last several years the study of dental caries has substantially improved our knowledge and understanding of this disease (Tanzer, 1995). Compelling evidence for conservative decisions regarding caries management and prevention has accumulated and should be integrated into contemporary cariology teaching programs (Löe, 1995). A comprehensive understanding of this science is essential to modern-day dental practice, especially with respect to caries prevention, operative dentistry and endodontics.

For more than a century, the widely-held perception that the disease and the destruction caused by the disease are one and the same has been an impediment to those who promoted the study of dental caries. In operative dentistry, the knowledge and skill required to repair damage have been at the center of attention. While the restoration of form, function and esthetics of teeth damaged by caries is a priority for dentists, it should no longer be the only priority (Krasse, 1996). Focusing on the disease, as well as the lesions it produces, is essential. Manipulation, elimination and/or compensation for predisposing factors before cavitation occurs provides an opportunity to avoid or delay surgical intervention and the restoration-rerestoration cycle. In this context, the operative phase of treatment becomes a means to an end; controlling the disease by eliminating retention sites for cariogenic plaque (Anderson, Bales & Omnell, 1993).

The recognition that dental caries is an infectious disease and should be treated as such is slowly gaining acceptance by the dental profession in North America (Edelstein, 1994; ADA Council on Access, Prevention and Interprofessional Relations, 1995). To those familiar with cariology, this is not a new concept , but unfortunately, cariology is not emphasized in many North American dental schools. Professors of cariology are a rarity, and separate departments or divisions with special responsibility for cariology are uncommon despite the fact that prevention and treatment of caries and its sequelae represent the main workload in general dental practice. Some dental students are not given the opportunity to study this disease, its etiology, the process or contemporary means of controlling the disease. In a profession whose expressed purpose is to establish and maintain good oral health, this deficit is unconscionable.

While the dental profession has gained an exceptional reputation for its efforts at disease prevention, ensuring patient compliance with conventional plaque control is required to obtain optimal results. In some cases, patients either cannot or will not comply. Therefore, an understanding of dental caries and treatment modalities that enable dentists to lower the cariogenic potential of dental plaque while increasing the resistance of enamel to future acid challenges should be important components of any dental curriculum (Baum, 1996).

This project represents an effort by the authors to determine the degree to which cariology has been included in the curricula of North American dental schools and what treatment modalities are taught in the clinical management of this disease.

## METHOD

A survey was designed to assess: (1) the number of teaching hours and organization in cariology; (2) the caries management philosophy taught; (3) the diagnostic threshold for surgical intervention and (4) the treatment alternatives implemented in North American dental schools. All responses were returned anonymously to the authors, but those requesting a report of the results were asked to include their name and address.

The survey was sent to all 65 dental schools in the United States and Canada. The requests for information were usually directed to the Chair of the Restorative/Operative Department or the Dean for Academic Affairs as listed in the 1999-2000 American Association of Dental Schools Directory of Institutional Members and Association Officers. In each instance, the addressee was requested to forward the survey to whomever was most likely responsible for the teaching of cariology.

## RESULTS

Forty-three schools (66%) responded to the request for information related to their teaching and treatment programs for dental caries. One reminder letter was sent out four weeks after the initial deadline had expired. Although the letter inviting the dental schools to participate also asked them to indicate why they did not want to respond, no survey forms were returned explaining the lack of a response. However, some voluntarily included their name and asked for feedback on the information received.

### Teaching Effort and Organization

Only three of the 43 responding schools had a separate department or division of cariology. In most dental schools, the faculty from several departments participated; operative and restorative faculty being most commonly involved (Figure 1). Eighteen schools reported a separate course in cariology, while the 25 remaining schools integrated their teaching of cariology with other teaching programs or courses. Based on responses from 21 schools, the mean number of hours devoted to cariology was 20.5, with a range of 2-81 hours. An average of 4.7 teachers participated in the teaching according to the responses from 24 schools; the range being 1-13 teachers. To a question that asked whether a specific textbook was being recommended for cariology, only eight responded affirmatively. The most commonly used textbook was that edited by Thylstrup & Fejerskov (1994).

### Teaching Philosophy

An antibacterial/non-surgical approach to the management of dental caries had been adopted by 26 of 43 responding schools, while 14 had not accepted this “medical model” of caries management and three declined to respond. Eight schools added comments to this question, which may indicate that changes in the teaching of cariology are occurring. One “no” respondent indicated: “Not for want of trying, but there are conflicts between the section of Operative and others.” Two of the “yes” respondents indicated: “Yes, although faculty cooperation is not 100%” and “philosophically, 100%, practically, 25% but moving towards 100%.” Caries risk assessment or the establishment of a cariogenic profile for patients was in place at 29 schools, while 14 did not include this information in the treatment planning of patients. However, diet analysis and/or counseling was taught by 39 of the responding schools.

Bacteriological tests were used by five of the responding schools to establish a baseline level for all dentate patients. Sixteen schools prescribed chlorhexidine mouth rinses to reduce the levels of bacteria associated with dental caries and the predominant regimen was 1/2 oz of 0.12% chlorhexidine twice a day for two weeks. Seventeen schools required the elimination of retention

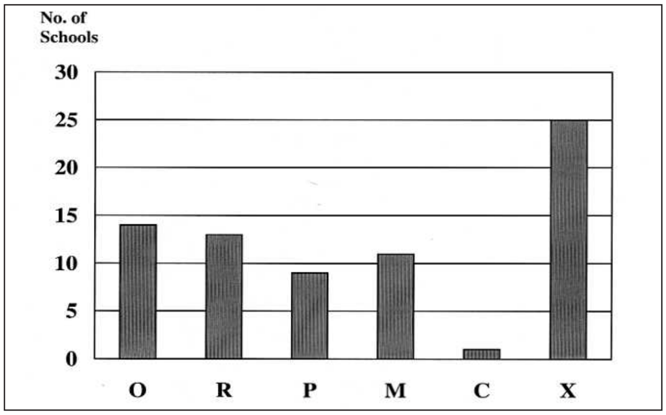


Figure 1. *Departments teaching cariology at 43 North American dental schools. Note that several departments are involved in some schools. Other department's (x) included departments of pediatric dentistry, community dentistry, general or comprehensive dentistry, oral biology, dental public health, oral pathology, periodontology. The defined departments were: O, operative; R, restorative; P, preventive; M, microbiology and C, conservative dentistry.*

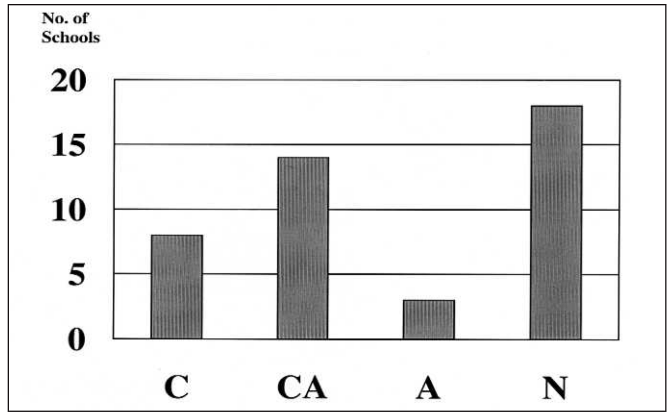


Figure 2. *Summarizes the responses relative to the use of fluoride varnish to treat or prevent dental caries. C, children only; CA, children and adults; A, adults only; N, no use of fluoride varnish.*

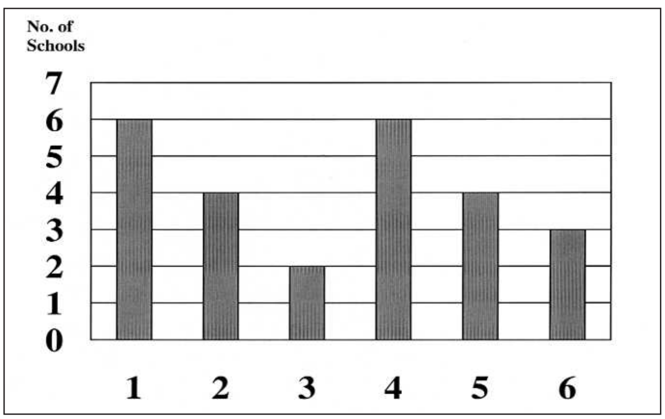


Figure 3. *Shows the points in time when 13 of the schools that use the bacteriological test take the culture: 1, prior to starting treatment; 2, immediately following treatment; 3, after two or three weeks; 4, after two or three months; 5, after six months; 6, after every recall visit. Note that some schools had two or three answers.*

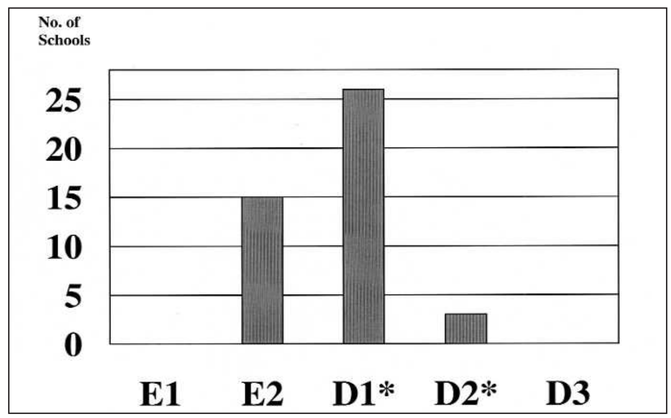


Figure 4. *Illustrates the radiographic threshold for operative intervention of interproximal primary caries lesions. E1, outer 1/2 of enamel; E2, inner half of enamel; D1, outer 1/3 of dentin; D2, middle 1/3 of dentin; D3, inner 1/3 of dentin. *Two of the 43 schools opted for two of the alternative answers (D1 and D2).*

sites prior to prescribing the chlorhexidine mouth rinse, 14 schools did not and 12 provided no answer.

Adjunctive fluoride, in addition to that in toothpaste, is taught as advisable by a majority of respondents for patients with active caries (Figure 2). Nineteen schools do not use fluoride varnish, but the majority of the 24 schools teaching its use recommend treatment for both children and adults.

Fifteen of 40 responding schools indicated the use of bacteriological tests to determine the efficacy of their disease management efforts. With regards to when these tests were administered, there was a distribution, from immediately following treatment to six months after treatment, and three schools reported the use of bacteriological tests at every recall visit (Figure 3).

### Diagnostic Threshold for Surgical Intervention

The reported radiographic threshold for surgical intervention of approximal primary lesions is shown in Figure 4. Fifteen schools advocate surgical intervention when the lesion has reached the inner half of the enamel. Twenty-seven schools teach that restorations should not be placed until the lesion has reached the outer-third of dentin, and two of these indicated both outer- and middle-third of dentin. Only one school teaches surgical intervention only when the lesion has reached the middle-third of the dentin.

A variety of techniques are taught for detecting occlusal lesions; frank cavitation and radiographs being the most common. Twenty-five schools also teach the use of an "explorer catch" as a detection method and 12 use stained fissures as evidence of occlusal lesions. Three schools reported using electronic devices to detect occlusal caries lesions. Twenty schools listed "other" criteria, visual inspection *per se* being the most common.

Twenty-nine of the responding schools teach the use of a "caries indicator" solution to assist in the removal of carious tissue. Eleven schools confirmed that they to not use these dyes and three did not answer the question.

A question related to the placement of sealants over pits and fissures with suspected active caries lesions resulted in 11 affirmative and 32 negative responses. A question asking whether the school teaches monitoring of non-cavitated, primary lesions produced the following responses to the alternatives provided: 17 stated always, 4 rarely, 1 never and 21 depending on the extent of the lesion.

The questions related to criteria other than radiographic to diagnose recurrent caries yielded variable responses. Five schools did not respond to this question and 38 others provided answers that are difficult to summarize in a representative manner. "Tactile explorer catch, open margins, visual signs, sensitivity symptoms and color changes" were frequently quoted, as were "demineralization and cavitation of restoration margins." Other remarks included "subjective physical assessment," "varies with the teacher" and "we are currently developing uniform criteria" or "currently, no criteria are used but new criteria have been developed and will be tested this term."

The curricula of dental schools also varied regarding teaching the monitoring of recurrent caries lesions: 9 indicated always, 12 rarely, 6 never and 16 responded that it depended on the extent of the lesions.

### Treatment Alternatives

Sixteen schools routinely repair, refurbish or partially replace existing restorations that present with localized defects. Twenty-five responded that they did not teach these alternative treatment modalities for defective restorations and two did not answer the question.

A question related to the routine removal of existing restorations prior to extracoronal tooth preparation resulted in the following distribution of responses to the alternatives provided: 7 always, 23 with few exceptions and 13 that it depends entirely on the condition of existing restorations.

The final question was related to requiring disease control (Phase I treatment) before allowing students to proceed with elective or prosthodontic treatment (Phase II treatment). Twenty-seven schools responded that they routinely required such treatment, while 16 did not.

## DISCUSSION

Cariology is a clinically relevant field with distinct links to basic science and, as such, provides the opportunity for basic scientists and clinicians to collaborate in a unique and mutually beneficial way to provide a scientific context for the practice of restorative dentistry. It clearly demonstrates the relevance of dental embryology and histology, microbiology, pulp biology and physiology and biochemistry to the clinical management of dental caries and to restorative dentistry (Thylstrup & Fejerskov, 1994). There is ample documented evidence upon which decisions can be made in the detection, diagnosis, treatment and prevention of dental caries. Since dental caries is an infectious disease (Fitzgerald & Keyes, 1960), the predisposing factors responsible for the disease should be identified for each patient. These factors can then be managed in such a way as to lower the risk of future caries incidence and/or the progression of existing lesions (Krasse, 1985). An oral environment can be established that will promote remineralization of non-cavitated lesions, avoiding or minimizing surgical intervention.

The 66% response rate was somewhat disappointing and may represent an indifferent attitude with respect to cariology in many dental schools. The fact that only eight of the responding 43 dental schools recommend a specific textbook in cariology also reflects a stoical position and possibly an indifferent attitude to this major area in dentistry, although it is realized that other textbooks used by students, notably in operative dentistry , cover some information related to cariology (Lundeen & Roberson, 1995; Schwartz & Hilton, (1996). However, the disappointing response rate was to some extent compensated for by enthusiastic responses from some schools; some even included details regarding their cariology course, lecture by lecture. Comments, such as "a cariology program is to be implemented" and "in progress," indicate that the situation is improving with regards to active teaching of cariology, both theoretically and clinically.

The great variation in time devoted to the teaching of cariology (2 to 81 hours) and the number of different departments involved and teachers participating, may reflect a lack of expertise or willingness to accept responsibility for teaching cariology. It should be recognized, however, that cariology is a practical subject that should be taught chairside. The paucity of up-to-date North American textbooks in cariology may also explain the lack of recommendations in this area. American cariology textbooks were published some time ago (Newbrun, 1978; Loesche, 1982; Nikiforuk; 1985). Only one has been revised within the past 10 years.

Only 60% of the schools had adopted an antibacterial/non-surgical approach to the management of dental caries and about the same percentage required evidence of disease control before allowing students to initiate complex restorative treatment. The evidence to support such an approach is strong (Mandel, 1994); and it is difficult to understand why some dental schools hesitate to promote this concept. Coincident with this apparent lack of support for an antibacterial/non-surgical approach to cariology, only 67% of the schools include a caries risk assessment in the treatment planning of patients. However, caries risk assessment (Reich, Lussi & Newbrun, 1999) was lectured on in most dental schools, confirming the findings by Yorty & Brown (1999) and although this topic had a clinical component, just over one-third of the responding schools in that study had graduation requirements or clinical competencies in caries risk assessment. On the other hand, the long established practice of diet counseling was taught by 91% of the schools.

Reports in the literature on the use of bacteriological tests as a means of risk assessment versus the monitoring of disease management efforts present very different results with regards to sensitivity for diagnosis versus specificity for assessing outcomes (Sugars & Sugars, 1995). An incomplete understanding of this difference may explain why only 12% of the respondents use these tests as an indicator for the efficacy of treatment.

Only 38% of the schools reported the use of chlorhexidine in caries management (van Rijkom, Truin & van't Hof, 1996) and the regimen most commonly employed was rinsing twice a day with a 0.12% chlorhexidine solution for two weeks. This reported use of chlorhexidine was much lower than the 76% reported by Yorty & Brown (1999) for US dental schools.

Fluoride, in addition to fluoride added to water and/or toothpaste, was recommended by virtually all responding dental schools, which agrees with the findings in another recent report (Yorty & Brown, 1999). A variety of topical fluoride regimens were recommended for use, including in-office fluoride applications, fluoride-releasing varnish, fluoride gels and over-the-counter, low concentration rinses. Overwhelming scientific documentation has demonstrated the benefits of topical fluoride in the prevention of caries and in the remineralization of non-cavitated lesions (Christensen, 1995; Truhlar, 1997; Stevens, 1996; Newbrun, 1999; Seppä, 1999) and this evidence has been included in many North American dental curricula.

Monitoring lesion progression depending on its extent (Ismail, 1997) is taught by a great majority of the responding schools. Less than 10% of the respondents rarely or never monitored lesions, either to assess caries activity or the efficacy of non-surgical treatment. It is, therefore, surprising that 35% of the schools teach surgical intervention based solely on radiographic evidence of caries limited to enamel (Elderton, 1993). However, 64% do not operatively intervene until a lesion has reached the outer-third of the dentin and one school does not teach surgical intervention until lesions reach the middle-third of dentin. These findings are in agreement with those reported by Yorty & Brown (1999) and should be noted not only by practicing dentists, but also by State Board Examiners (Christensen, 1995).

Sealing suspected active caries in fissures was accepted by only 27% of schools disregarding the findings of Mertz-Fairhurst & others (1998), who sealed in resin based composite material over extensive occlusal lesions and found no evidence of lesion progression even after 10 years.

The detection of caries lesions is most often attempted by conventional means using radiography and visual inspection; 55% of the respondents also use an "explorer catch" as a detection method, although the basis for this approach has been questioned (Newbrun, 1993). Stained fissures were reported as diagnostic evidence of caries activity by 24% of the responding schools, but the justification for this approach is also questionable. Newly developed methods (Stookey, 1996; Ricketts, Kidd & Wilson, 1995) for detecting occlusal lesions were reported by only three schools and, while the benefit of using a dye "caries indicator" to assist in the removal of carious tissue is a debatable issue (Sato & Fusayama, 1976; Kidd, Joyston-Bechal & Beighton, 1993), 67% of the respondents teach their use. The use of these dyes may also lead to excessive removal of tooth tissue.

The variable responses to a request for criteria used to diagnose recurrent caries is a reflection of the uncertainty associated with diagnosing such lesions. A recent review of the literature on recurrent caries, supported by clinical case presentations points out the meager scientific basis and the ambiguity associated with this very common clinical diagnosis. Much more clinical research is needed to provide a sound basis for diagnostic decisions regarding true caries activity versus stained margins and other non-carious defects at the margins of restorations, especially those that are isolated or restricted to small areas of large restorations (Kidd & others, 1993). It is disturbing that an explorer "catch" is still such a predominant diagnostic indicator for recurrent caries lesions since scientific evidence does not support its validity. According to Mjör & Toffenetti (2000), the best clinical criteria for diagnosing recurrent caries lesions are cavitation, consistency and hardness of the mineralized tissues and the color of dentin and enamel, that is, criteria similar to that for primary caries lesions. They recommended that consistency/hardness supersede color in diagnosing recurrent lesions and emphasized the need to differentiate between stained restoration margins, crevices and active versus arrested recurrent lesions. Plaque accumulation especially at gingival margins of restorations has also been shown to predispose to recurrent caries (Özer, 1997).

Long-term studies on the advantages of refurbishing techniques that might include enameloplasty, repair and partial replacement of existing restorations are lacking, and only 39% of the dental schools in North America teach this approach as an alternative to total replacement. Refurbishing of existing restorations can extend their useful life, slowing or avoiding the restoration-rerestoration cycle (Brantley & others, 1995; Oleinisky & others, 1996; Osborne & Summitt, 1998). It also appears that removing a small portion of a restoration to make a proper diagnosis of the extent of a defect is justified. If the defect does not extend under the restoration and the margins around the localized defect can be cleared of pathology, repair must be the treatment of choice provided the retention of the remaining restoration is not jeopardized and satisfactory esthetics can be maintained. Furthermore, anecdotal information indicates that some ditched margins of amalgam and composite restorations can be treated with a fissure sealant but no long-term data appears to be available. Since 69% of all responding schools indicated that existing restorations were always, or with few exceptions, replaced prior to the placement of extracoronal restorations, it is apparent that uncertainty persists with regards to the quality of many existing restorations.

A fairly rapid increase in the number of established departments of cariology in US dental schools was predicted more than 20 years ago , but this development has not occurred. Apart from caries epidemiology, the lack of a substantial emerging cariology research base may partially explain the present situation in this country. The fact that cariology is not a recognized specialty in North America may also contribute to the lack of attention to this area. Historically, specialties foster research that provides a scientific basis for the didactic and clinical teaching in that given area of specialization.

It is generally accepted that dental caries and periodontal disease are the two most common dental diseases, but a disproportionate relationship exists between the two areas in research activity, teaching effort at dental schools and clinical implementation of modern treatment strategies. If one considers the large number of professors at various levels in periodontology in North American dental schools versus the handful of professors in cariology and compares that to the time spent in general dental practice treating caries versus that time spent treating periodontal disease, this disproportionality is astounding.

## CONCLUSIONS

Forty-three schools (66%) responded to the request for information related to their teaching of cariology. The survey indicates that several schools have developed cariology courses and implemented clinical programs to teach the medical management of dental caries. From notes and comments attached to the survey forms, it is apparent that some of these courses are comprehensive and have been in place for some time. Those responsible for the teaching seem eager to share their experience with others. Some cariology programs are in more formative stages, with respondents indicating that curriculum revision and/or faculty development is in progress. However, many cariology programs at North American dental schools appear to lack the stringency expected in this major area of clinical dentistry. In a majority of the schools surveyed, the responses or lack thereof indicate a range of both interest and qualifications in the teaching of cariology and also in the implementation of treatment strategies for dental caries.

Dental cariology as an important basic science and clinical entity needs and deserves development and emphasis in the dental curriculum. Data available today justify evidence-based teaching of cariology (Benn & others, 1999). A working knowledge of the multiple factors involved in cariogenicity is a prerequisite to any meaningful attempt to control this disease. Even those students who are taught to rely exclusively on plaque removal for the prevention of dental caries, need and deserve the fundamental knowledge base that cariology provides. Only with this knowledge will tomorrow's dentists be able to recognize, appreciate and implement new, more effective treatment modalities in a timely manner.

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# Custom Matrix Adaptation with Elastic Cords

DCN Chan

**Clinical Relevance**

Proper placement of the matrix and wedge is critical to the success of Class II and III amalgam and resin composite restorations. Improper placement of matrix and wedges can result in poor contours or contacts, overhangs or weakness resulting from poorly condensed restorative material. Occasionally, a clinician encounters a concavity at the gingival cavosurface margin of a Class II cavity, which makes this area difficult to restore properly with amalgam or resin composite. This paper describes a technique for adaptation of the matrix in cases where the gingival cavosurface margin involves a concavity and other anatomical variations.



## INTRODUCTION

Interproximal dental wedges are commonly used in Class II and Class III restorations. They force teeth apart enough to compensate for the thickness of the matrix, support the matrix against packing pressures of filling materials, prevent matrix displacement or filling excess/overhang and preserve anatomical tooth and tissue contours of the interdental space (Qualtrough & Wilson, 1991). Occasionally, concavity at the gingival cavosurface margin of a prepared cavity makes this area difficult to restore properly with amalgam or resin composite (Figure 1). Such concavities are frequently seen in the cervical area of maxillary premolars, in the mesial roots of mandibular molars and occasionally in the distal aspects of maxillary molars.

Existing preformed triangular-shaped wooden wedges are not adaptable to concavities and other conditions such as root caries or irregular tooth contours. Other wedge material, such as clear acrylic dental wedges used with light-cured composite fillings, are difficult to adapt and adjust. New innovative methods are frequently proposed to tackle such challenges (Ireland, 1985; Khera & Swift, 1989; Woodmansey, 1998).

A new product, Flexi Wedge (Common Sense Dental Products, Inc, Spring Lake, MI), has been specifically designed to solve some of the problem. However, the

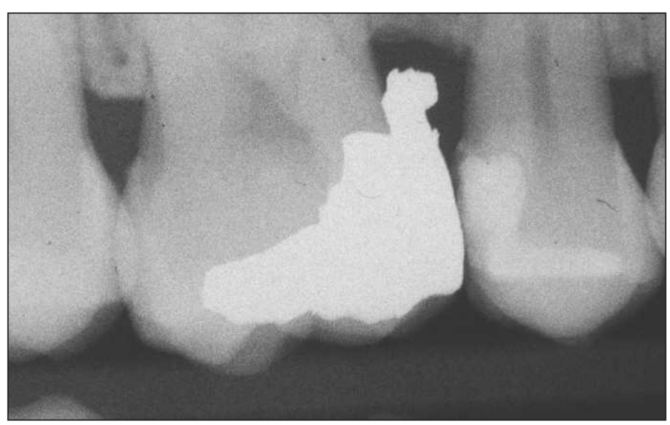

Figure 1. *Bitewing radiograph of an MO amalgam restoration on a maxillary molar. Excessive overhang is the result of incorrect wedging. Destruction to the periodontium is evident.*

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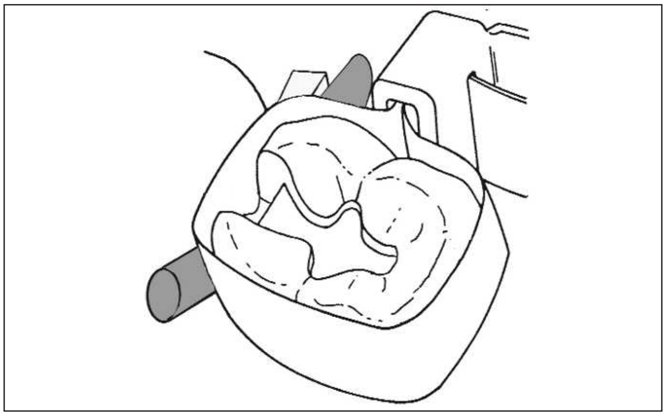

Figure 2A. *Schematic diagram of matrix, wedge and elastic cord placement. Note concavity in the center of the proximal box is sealed with no gap present between the matrix band and tooth cavosurface.*

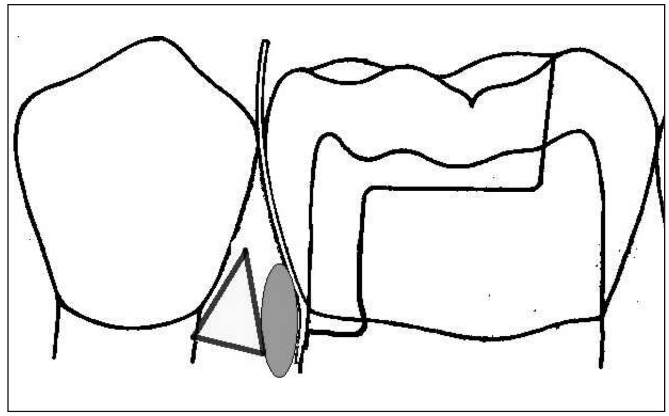

Figure 2B. *Schematic diagram showing a cross-section of the relationships among matrix, wedge and elastic cord. Proper interproximal contour can be reproduced by careful burnishing.*

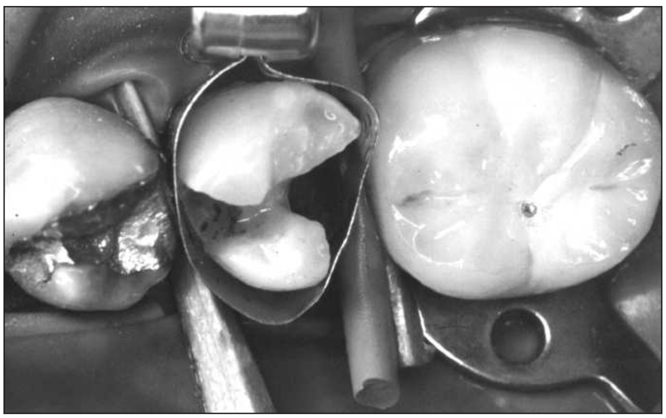

Figure 3A. *Clinical case of the elastic cord and wedge combination* in situ*. The distal box of the premolar extended deep gingivally; additionally, the distolingual proximal wall is missing. Correct matrix adaptation has been accomplished with a Wedgets placed between the wedge and the matrix.*

Figure 3B. *A lingual view of the assembly. Note that the Wedgets has been pushed against the matrix band and conforms to the tooth contour.*

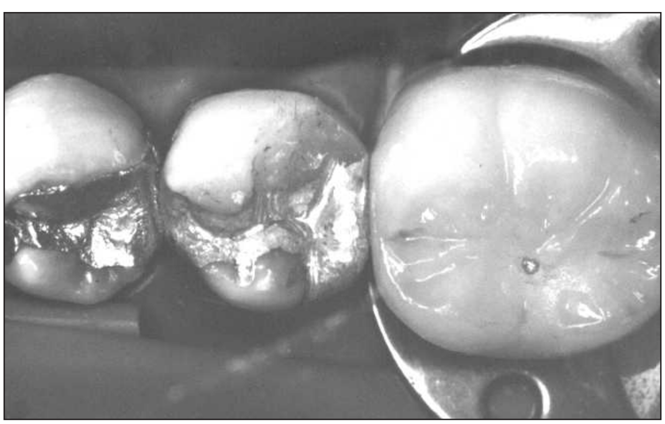

Figure 3C. *Occlusal views of completed restoration with proper contour.*

technique for the placement of Flexi Wedge is quite different from wooden wedges and requires special college pliers, hemostat, Howe pliers or a similar-type instrument. Strong driving force, plus a gentle up-and-down rocking motion, is required to drive the wedge into the correct position.

This paper offers a simple solution for a few of those clinical situations where difficulties are encountered. The solution lies in use of an elastic cord material capable of deforming sufficiently to take on and conform to any concave aspects of adjacent tooth surfaces. Such an elastic cord is readily available in rubber dam procedures. The clinician can employ the conventional wooden wedges for this technique without extra equipment or expense for new products.

## TECHNIQUE

Figures 2-4 illustrate the technique of using a combination of elastic cord and a hardwood wedge to adapt a thin metal matrix band to conform intimately to irregular, highly curved, concave or convex tooth surfaces.

Figure 4A. *A similar clinical case of the elastic cord and wedge combination in use for a maxillary molar.*

Figure 4B. *4B Occlusal views of completed restoration with proper contour.*

The elastic cord (Wedgets, Coltene/Whaledent Inc, Mahwah, NJ 07430) used is stretchable and made from natural latex rubber designed to hold the dental dam in place during treatment. This cord dispenses and places like dental floss. It is available in extra small, small and large sizes.

1. After cavity preparation is completed, pre-select a wooden wedge that will fit into the interdental spaces.
2. Place the extra thin metal matrix on the tooth and adapt it in the usual manner; loosen the retainer one-half turn to make the metal matrix flexible enough for adaptation at the concave gingival cavosurface margin.
3. Place the Wedgets interproximally; select a size that will fit tightly between the matrix and tooth when compressed.
4. Apply the wedge(s) with adequate pressure. The wooden wedge will engage much of the interdental space and push the Wedgets to deform sufficiently and conform to any concave aspects of adjacent tooth surfaces (Figure 3A & B, Figure 4A). Make sure that the matrix is tightly adapted against the gingival cavosurface margin and burnish it from inside for the desired interproximal contours and contacts.
5. Once the gingival area is sealed, burnish the proximal box towards the contact area, making the cervical part of the matrix more directly accessible.
6. The prepared cavity is ready to be restored.
7. Oftentimes, taking special care to seal the gingival portion would mean that other areas might not be adapted as ideally as preferred. Notice that the occlusal portion of the metal matrix is not in contact with the adjacent tooth in Figure 3B. After restoring with amalgam up to but shy of the contact area, progressively loosen the retainer one to one-half turn to provide for proper contact and contour.
8. Restore the rest of the restoration back to proper contour (Figure 3C, Figure 4B).

## ADDITIONAL CONSIDERATIONS

Wedgets is a stretchable cord made from natural latex rubber that might cause allergic reactions. Check medical history again to make sure that the patient is not allergic to latex before applying the cord.

Although the combination of Wedgets and a wedge is adequate to seal the gingival interface, such a combination may not provide enough separation of tooth to compensate for the thickness of the 0.002-inch matrix band. A dead soft thin metal matrix band (0.0015-inch) is recommended for use in this technique. A softer metal can also be burnished and better adapted to the concavity.

Condensation force of approximately 7 kg has been recommended for amalgam restoration to ensure a properly condensed mass. If such a force is directed at the matrix/tooth interface supported solely by the Wedgets material, the interface might not be strong enough. If the concavity occurs deep on the root surface, an open-sandwich technique is recommended. In such a case, the gingival area is restored with a glass ionomer material first and amalgam condensed on top of the cured glass ionomer layer.

For unusually deep concavities or very irregular tooth contours, two strands of Wedgets and double wedging may be required. One can also use LC blocking resin (Ultradent Products Inc, South Jordan, UT 84095) to provide the additional extension. The same technique as reported by Khera and Swift (1989) can be followed except that the bonding resin is substituted by the LC block-out resin.

## SUMMARY

Proper placement of the matrix and wedge is critical to the success of proximal amalgam and posterior resin composite restorations. This paper has presented an easy technique for adaptation of the matrix in cases where the gingival cavosurface margin involves a concavity. Special case considerations were also discussed.

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A Faculty Advisor should be named, and he/she should co-sign the application. The application must be submitted by December 15, 2001 to:

Academy of Operative Dentistry,
Research Committee
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### 2002 Meeting of the Academy of Operative Dentistry European Section

The 2002 meeting of the Academy of Operative Dentistry European Section will be hosted by the University of Nijmegen College of Dental Science in Nijmegen, The Netherlands. The meeting, to be entitled "Adhesive dentistry today. Transfer of research into practice" will be held December 5th-7th, 2002. Details may be obtained from:

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