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

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EDITORIAL

Operative Dentistry Education: The Pendulum ... and the Pit

All of us in the dental profession, and particularly those in dental education, have watched the pendulum of change swing continually from extreme to extreme. Buzz words like "objectives" and "quality assurance" are replaced by "outcomes assessment" and "medical model"; "stomatologist" makes way for "oral physician." Each time the direction of the swing is determined by various forces such as economics, technology, epidemiology, and/or politics. The momentum is provided by (one hopes) well-meaning colleagues who have their own personal vision of what is best for our profession, our patients, or themselves.

Currently there are a number of trends and forces that are having an impact on operative dentistry curriculum. Decreased funding support for higher education and increasing costs have resulted in dental school closures, department restructuring, a reduction in trained and experienced clinical faculty, and a strong emphasis on the hiring of research-oriented PhD's with a proven record of grant support. Dental school clinics are being reorganized into comprehensive practice areas and are looked upon more as income-producing enterprises than as educational experiences (see editorial, *Operative Dentistry* 20(5), 1995). Educators are asked to do more with less on a regular basis.

Additionally there is a widely publicized swing toward the integration of dentistry and medicine at several levels and a strengthening of training in the basic sciences and in the use of the scientific method. This, coupled with the rapid expansion of knowledge and scientific technology in all areas, has put tremendous strain on the utilization of available time in an already crowded curriculum. Although most of us agree that the myriad aspects of our profession are of equal importance and value, colleagues find themselves in so-called "turf" wars because of the increasing difficulty in fitting everything into the traditional four years. The process of maintaining balance by eliminating equal amounts of "old" information each time you add "new" has become impossible, and dentistry does not have the luxury of medical education in positioning surgical skills training in postgraduate internship and residency programs.

The net result at many schools of dentistry has been a degradation of the quality of clinical education in operative dentistry. What was once the foundation of our profession from which all the specialty areas were created is frequently relegated to trade status. Curricular time is deleted in technique courses, and students are expected to gain the necessary understanding of tooth morphology and occlusion while treating patients. Knowledge of dental materials often comes from reading the manufacturer's instructions for a particular product. Departments of Operative Dentistry are rapidly becoming extinct, and the discipline may not even exist as an official division in larger Restorative Departments. Faculty with advanced training or postgraduate degrees in operative dentistry are also a vanishing breed. Clinical instructors are frequently hired as "bodies" to monitor the students doing operative procedures and may be new graduates themselves with little clinical experience to share with their students.

Dentistry has done a tremendous job in its efforts in caries prevention and public health education. Caries incidence and tooth loss have been dramatically reduced in the last few decades and, with the potential advances in immunology, genetics, and molecular biology, may become a footnote in history. However, operative dentistry continues to be the primary focus of general dental practice and, if anything, has increased in scope and complexity, with the greater retention of the natural dentition, need for replacement of aging restorations, growing interest in cosmetic therapies, and the increasing variety of treatment techniques and materials available. If today's dental students are not thoroughly trained in operative dentistry, who will provide quality restorative care to the huge existing population requiring these services? Unfortunately the pendulum swing seems to be pushing excellence in operative dentistry education deeper and deeper into a bottomless pit.

It is said that "dental education has arrived at a crossroads" and that required educational reform should "equip dental education and dentistry in general to face a future that will be quite different from the past" (*Journal of Dental Education* 59(1):6-15, 1995). These far-reaching goals are laudable in theory, but some of the current directions in implementation are short sighted and can result in practitioners who are trained for a vision of the future but are unprepared to meet the needs of a very real present.

MICHAEL A COCHRAN
Associate Editor

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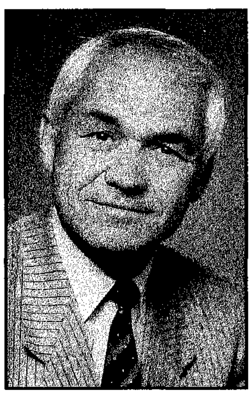
BUONOCORE MEMORIAL LECTURE

Michael Buonocore

The Postamalgam Age

FELIX LUTZ



INTRODUCTION

Two important dental anniversaries occurred in 1995. Forty years ago, in 1955, the milestone paper describing a simple method of increasing the adhesion of acrylic fillings to enamel was published by Michael G Buonocore (Buonocore, 1955). This paper ushered in the beginning of the adhesive technique in dentistry and, with a bang, methacrylate chemistry acquired great importance. This subsequently became dimethacrylate chemistry (Bowen, 1962) and formed the basis of current resin composites, compomers, luting composites, and adhesive systems, and was a prerequisite for visible light cure. And 20 years ago, in 1975, adhesive cavity preparations for anterior and posterior composite restorations were conceived, and the first salvo for adhesive dentistry was fired (Lutz, 1975).

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Currently, dentistry is further characterized by the fact that the amalgam age is fading (BIAM, 1994). Certainly this is progressing at different rates in different parts of the world; nonetheless, the countdown on the amalgam age is running. Operative dentistry is on the threshold of the postamalgam age, which is based on tooth-colored restorative materials and adhesive dentistry (Krejci & Lutz, 1995). Health insurance companies, national dental societies, dentists, and patients all favor a smooth transition from the amalgam age into the postamalgam age without disadvantages to oral health care of the population. This critical transition from the amalgam age to the postamalgam age is surely worthy of consideration.

STATE OF THE ART

It is now 40 years since the first paper on adhesion to dental hard substances was published and 20 years since the first adhesive cavity preparation was documented. The current state of development of adhesive dentistry and tooth-colored restoratives can be summarized as follows:

•Adhesive dentistry: The missing link remains the adhesive cavity preparation for approximal surfaces in posterior teeth. The limiting factor is not the cavity design, but the technical procedure itself;

•Amalgam substitutes: There are still no amalgam substitutes for stress-bearing permanent restorations in permanent teeth;

•Amalgam alternatives: Although all standard indications are covered, the majority of the current operative techniques are complex, demanding, and time consuming. Consequently, the resulting restorations are rather expensive.

With such statements one may pass to the order of the day and let the dental material people solve all the problems. Because the ideal restorative material will only be developed sometime during the next century, this way of thinking suffices for those clinicians who believe or anticipate that amalgam will remain unrestricted in use and will continue to be uncritically accepted by the vast majority of patients for at least another decade.

THE POSTAMALGAM AGE

In reality, amalgam has already become an embattled material because of its many shortcomings (Barbakow & others, 1994; BIAM, 1994):

•The operative technique with amalgam is based on mechanistic principles. The box-shaped cavity preparation is not tooth friendly to either healthy enamel or dentin, and the crown is weakened. The latter will remain so, at least as long as amalgam bonding fails to become clinically relevant in so far that more conservative cavity designs become feasible (Barbakow & others, 1994);

•Marginal disintegration of amalgam fillings is material inherent and ultimately limits the longevity of restorations (Barbakow & others, 1994);

•Environmental contamination can be accurately measured. This induced Sweden and Denmark to opt out of amalgam by 1997 and 1999 respectively (BIAM, 1994);

•Esthetics cannot objectively be assessed. It is a matter of subjective rating and a major reason why an increasing number of patients or consumers are already voluntarily in the postamalgam age;

•The toxicological and allergenic potential of amalgam can no longer be scientifically assessed. Mercury fundamentalists among medical practitioners and dentists and the so-called amalgam victims have irreversibly vilified amalgam. Having been more or less blackmailed by this lobby, the German authorities have barred the use of amalgam in pregnant women and as a core build-up material. In Germany, its indication is now restricted to stress-bearing fillings in permanent teeth (BIAM, 1994).

Consequently, a relevant number of patients and consumers, at least in Europe, are already in the postamalgam age, either of or against their own free will. Generally, dentists who must now provide dental care without amalgam or, even worse, without metal-based restoratives, are confronted with five major problem fields. These include education, restorative concepts and teaching competence, costs and economic aspects, materials and operative techniques, and prevention and maintenance care.

Education

The basic question is whether there is a need for education at all. This question is best answered when one considers where operative dentistry currently stands and in which direction it should head. The most commonly practiced operative dental procedures involve placing amalgam fillings and luting crowns. Both are based on mechanistic principles, and the thought processes are primarily reparative. In contrast, the goal for using tooth-colored restorative materials is to place invisible, maximally conservative, adhesive restorations that in some aspects are even preventive (Greenspan & others, 1995). Prerequisites for this include preventive thinking, mastering adhesive dentistry, handling resin-based materials, and an excellent knowledge of light-curing principles. It is obvious that with this list of prerequisites the average knowledge and skill of a "drill-and-fill" dentist totally obstructs a smooth and successful transition into the postamalgam age. However, a significant fact can be learned from the amalgam era. It has been shown that the operator is the single most important factor influencing the quality and longevity of restorations. This has been proven by the results of several long-term studies with amalgam that have recently been summarized (Barbakow & others, 1994). This indicates that there is an undoubted and urgent need for education that must include participation experience. Also clinicians who are mentally confined to mechanistic principles need some kind of brainwash to help them rethink their operative procedures.

The magnitude of this educational problem is frustrating and becomes even more obvious when time projections and teaching efficiency are considered. A projection based on the current conditions in Switzerland indicates the following: Assuming the four dental schools fully master the theory and the practical aspects of adhesive dentistry and begin teaching tooth-colored restoratives from the autumn of 1995, then by 1998 there will be approximately 80 dentists, 50% of them women, adequately trained in tooth-colored restoratives. This represents only 2% of the clinicians active in the profession. By the year 2000 this figure will increase to 6%, and 10 years from now, in 2005, it will make up 16% of the active clinicians, at best. From our experience, only every third practitioner who attends a practical continuing education course on tooth-colored restorations manages the transition into the postamalgam age. If continuing education is intensified and a sensationally high number of clinicians, say 45%, will attend such courses during the next 10 years, then approximately one-third of all practitioners, at best, will be adequately prepared for the postamalgam age by the year 2005. The calculation clearly shows that the time necessary for the introduction of new restorative concepts has been vastly underestimated, in particular when high-quality standards must be obtained and different, nonmechanistic thinking is a prerequisite (Greenspan & others, 1995).

Restorative Concepts and Teaching Competence

Education in the field of tooth-colored restoratives cannot begin before the concepts of the procedures are in place and the teachers themselves are fully competent. Such restorative concepts must be based on scientific facts, on controlled clinical tests, and on well-planned teaching methods. Furthermore, the teachers must have the necessary skill, experience, and knowledge. Related practical courses must be conceived and organized. Again, the time required for this is frighteningly long. The restorative concepts must be practical, considering the prevailing local needs and demands. Consequently, the concepts may differ widely from country to country and cannot simply be adopted from other countries or institutions without being evaluated. Important modifying parameters that aid or deter the concepts include: preventive programs and care, dental awareness and a general level of information of patients, consumer demand, aspired restoration quality and longevity, level of competence of the dental workforce, technical infrastructure, tariff system and mode of payment for services, and gross national product (World Health Organization, 1987).

Costs and Economic Aspects

Costs and economic aspects, although totally unacceptable factors from an ethical standpoint, remain dominant (World Health Organization, 1987). Amalgam restorations are relatively cheap worldwide, and regardless of quality, are criminally underrated. Consequently, amalgam alternatives such as composites, composite inlays, and ceramic inlays are markedly more expensive. In Europe, for instance, amalgam alternatives are completely incompatible with the current national dental insurance systems. This is why the development of amalgam substitutes is so urgent in several European countries to ensure dental care in the near future.

The importance of pricing amalgam restorations may be illustrated by the following two examples: In Germany private practices aim at returns of DM 350 to DM 400 per hour. According to the current tariff system, a MOD amalgam restoration fetches DM 50. Consequently, the time allowed to place an MOD amalgam restoration is 7 minutes and 30 seconds. It is thus clear that the German national dental insurance system is incompatible with either amalgam alternatives or amalgam substitutes. In fact, it is also currently incompatible with amalgam. As a result the problems that German dentistry will be confronted with are completely insurmountable, particularly if the use of amalgam is further restricted. And in Switzerland, the cost of amalgam restorations is high. The time allotted for MOD restorations in the latest tariff is 50 minutes for an amalgam filling, including the second appointment for the polishing. The time allotted for a composite MOD is 56 minutes, 116 minutes for inlays made at the chairside and 132 for lab-made inlays, requiring two appointments (BIAM, 1994). These time frames do allow high-quality dentistry. Furthermore, in Switzerland, the difference in costs between amalgam and direct composites is a modest 13% because of the high rating of amalgam restorations (Barbakow & others, 1994). Therefore, the transition into the postamalgam age is unlikely to be linked to a financial disaster in Switzerland. Nevertheless, the educational problems are enormous and will remain so for the foreseeable future. In contrast, the costs of inlays, including the lab work, are three to four times higher than that of amalgam. Therefore, the strong trend towards direct resin composite restorations needs no further explanation.

Materials and Operative Techniques

The priorities are set, and the major priority is to develop amalgam substitutes. The second priority is to simplify the use of amalgam alternatives without compromising the restorations' high quality. Basically, this means that the properties of amalgam substitutes must be improved to produce a more stress-resistant marginal adaptation, and/or the caries-protective potential must be significantly increased. The next priority involves developing and marketing stronger light-curing units that can be automatically reset to preprogrammed energy outputs (Nomoto, Uchida & Hirasawa, 1994; Uctasli, Hasanreisoglu & Wilson, 1994; Watts & Cash, 1994). These new curing units should ensure an optimal marginal adaptation and full cure for different types of restorations such as direct fillings, inlays, and crowns.

However, the list of required improvements is decidedly longer for the amalgam alternatives. The polymerization kinetics of resin composites still need optimizing to achieve a 90 to 100% excellent and stress-resistant margin with more user-friendly placement techniques (Eick & others, 1993; Jendresen, 1993). The currently available one- or two-component adhesive systems comprising one component to condition or prime enamel and dentin and another component or the same in a second application to prime and bond must still be clinically evaluated. Luting composites must still be formulated with a two-step curing system and specific chromatic properties to enable a two-phase polymerization. This will allow an easy, nondestructive removal of all overhangs while the material is still in a gel-like state. Furthermore, this excess material would be easily identified because of its inherent transient contrast coloring. Another option is to lute workpieces using high-viscous light-curing luting resin composites with stronger curing lights and ultrasonic devices. Such a technique enables an easy removal of the pasty, nonflowing excess material before curing. As far as ceramics are concerned, it is important to develop more resilient and less abrasive glass ceramics or porcelains (Krejci, 1992; Krejci & others, 1993).

Prevention and Maintenance Care

Generally, amalgam restorations need little self-care and almost no maintenance, although it is well known that good oral hygiene and regular restoration maintenance significantly increases the longevity of amalgam restorations (Barbakow & others, 1994). However, the situation with amalgam alternatives is totally different. The amalgam alternatives require good self-care, preventive care, and professional restoration maintenance to ensure clinical success (Ferrari, Bertelli & Finger, 1993). The oral hygiene should include the daily use of approximal mechanical cleaning devices such as floss, picks, or interdental brushes. The restorations need refinishing, and dental hygienists should be aware of the fact that hand instruments, air-powder abrasives, and cleaning pastes are ruinous for tooth-colored restorations (Lee, Lai & Morgano, 1995).

THE REVOLUTION IN OPERATIVE DENTISTRY

A revolution in operative dentistry is unfolding that is characterized by the doom of the amalgam mentality, the rise of adhesive dentistry, and the sluggishness of the transition from the amalgam to the postamalgam age.

The term "amalgam mentality" implies a reparative mechanistic concept of curing caries with little know-how and modest skills (Greenspan & others, 1995). Dentistry certainly still has a place for such an operative approach. This concept is indicated for people with little dental knowledge, for patients who are disinterested in their dental health, for underprivileged people, or for people in an oral health care system that has restricted personal, financial, or material resources. Consequently it would be totally counterproductive to prematurely phase out amalgam (BIAM, 1994; Council on Dental Materials, Instruments and Equipment, 1994). But by adhering to the amalgam mentality, it will never be possible to promote and develop the knack of placing high-quality tooth-colored restoratives.

Adhesive dentistry stands for a prevention-oriented, minimally invasive high-quality dentistry. The operative procedures are based on adhesive cavity preparations, bonding and resin composites, partially in conjunction with ceramics. The higher costs per tooth-colored, preferably invisible, and long-lasting bonded restoration are compensated for by a decrease in the number of restorations to be placed due to prevention. This type of dentistry results in better oral health and serves the majority of the population significantly better than the all-too-often-used amalgam-oriented drill-and-fill disservice (World Health Organization, 1987).

The sluggishness of the transition is made obvious by the simple calculation discussed earlier that clearly showed that the time necessary for the transition from amalgam-oriented dentistry to adhesive dentistry is much longer than previously anticipated. There is also no doubt that practitioners in most countries are too poorly prepared in adhesive dentistry, so that the patients/consumers cannot be properly treated with tooth-colored restorations (BIAM, 1994). To be more outspoken, it is imperative to speed up the transition from amalgam- to adhesive-based dentistry. In fact, too much time has already been lost. The question that should now be posed is, How did operative dentistry get in this uncomfortable situation? At least four reasons can be suggested:

- The Santa Claus philosophy, or the dream that one day a wonder restorative will be available to the profession;
- The destructive testing of newly developed dental materials (Lutz, 1993);
- The lack of clinical concepts; and
- The widespread trend of rejecting new clinical concepts, allegedly because of the lack of clinical evidence. In fact the rejections are made because of inertia or sheer laziness, the lack of the necessary skills, or because of economic reasons.

PLAN OF ACTION

What can be done to rectify the situation? There are three strategies that can be recommended because they are successful, or at least promising, as proven by the fact that Switzerland is about to make a smooth landing in the postamalgam age. The first strategy is to buy time to ensure that amalgam remains available for use as a restorative material for stress-bearing fillings in permanent teeth at least for another 5 to 10 years, and furthermore to ensure that amalgam is priced according to the time required to achieve a well-defined high-quality standard. The second strategy is to set the quality standard for tooth-colored restorations and to develop and clinically evaluate operative concepts suitable for tooth-colored restorative materials that could fit into the prevailing field, and then to teach these concepts. The latter includes both modifying the undergraduate and graduate curriculum and offering practical continuing education courses for practitioners. The third strategy is to screen every possibility that might simplify the operative technique for tooth-colored amalgam alternatives without jeopardizing the quality of the restorations and to encourage the development of amalgam substitutes.

CONCLUSIONS

It is a fact that in operative dentistry all standard indications are currently covered by tooth-colored metal-free restoratives. Furthermore, proven clinical concepts for tooth-colored restoratives are already in place, and these concepts almost totally comply with the rules pertaining to adhesive dentistry. In some areas, the postamalgam age has already begun or it can be initiated whenever or wherever desirable, appropriate, or necessary. The limiting factors are not technical, but are concentrated at the teaching level or are influenced by the prevailing health care systems. The amalgam age will definitely cease or may be brought to an end when amalgam substitutes for stress-bearing restorations in permanent teeth are available.

(Delivered 23 February 1995)

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A Histopathological Study of Direct Pulp Capping with Adhesive Resins

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Clinical Relevance
The severity of pulpal response to direct pulp capping using four different adhesive resins was closely correlated to the degree of observed microleakage.

SUMMARY

This study evaluated the histological pulp responses of four different adhesive resin systems placed directly on exposed pulp tissue. Gap formation between the respective resin and cavity walls was observed and correlated to the pulpal response. Occlusal cavity preparations creating mechanical pulp exposures were prepared in molars of wistar rats. Preparations were filled using one of the following resin systems: 1) Superbond C&B system, 2) Clearfil Liner Bond system, 3) Tokuso Light Bond system, and 4) Scotchbond Multi-Purpose One All system. Although there were no significant differences in the pulpal responses after 3 days, significant differences were observed after 7 days. Results showed that the Superbond C&B system induced only a slight initial reaction, while secondary dentin was observed at the 30-day postoperative evaluation period. The Clearfil Liner Bond system showed a slight initial reaction to the materials, but exhibited slight pulpal necrosis and formation of secondary dentin at the 90-day evaluation period. The Tokuso Light Bond and One All systems showed severe pulpal reactions at all evaluation periods with no formation of secondary dentin. Microleakage formation correlated with the histopathological responses. Superbond C&B exhibited no microleakage, and only slight microleakage was observed when the Clearfil Bond system was used. The Tokuso and One All systems exhibited a wide area of microleakage. Further in vivo study evaluating the clinical use of adhesive resins for pulp capping is necessary to determine which resin systems may be used for direct pulp capping without incurring severe damage to pulpal tissue.

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INTRODUCTION

Pulpal irritation or necrosis after restoration using dental resin is a major problem accompanying the use of resin restorative materials. The material toxicity of dental resins was proposed as the main factor responsible for severe pulpal responses

(Langeland & others, 1966; Langeland, Dogon & Langeland, 1970; Stanley, Swerdlow & Buonocore, 1967; Stanley & others, 1972; Sayegh & Reed, 1969). However, it has also been reported that the penetration of bacteria and their products into the pulp through marginal microleakage between resin restorative materials and the cavity wall causes pulpal irritation (Brännström & Nyborg, 1971, 1972, 1973; Going, 1972; Skogedal & Eriksen, 1976; Vojinovic, Nyborg & Brännström, 1973; Inokoshi, 1980; Inokoshi, Iwaku & Fusayama, 1982; Fujitani, 1986; Otsuki, 1988).

The lack of adhesiveness to tooth substrate, especially dentin, causes this marginal microleakage. Some improved adhesive resins with high adhesiveness did not cause pulpal irritation in deep cavities close to the pulp (Matsuura & others, 1987; Stanley, Bowen & Cobb, 1988; Hosoda & others, 1989) and are used as lining materials for amalgam restorations (Ueno & others, 1989; Masaka, 1991).

Direct pulp capping with adhesive resin on exposed pulp has been suggested, providing marginal microleakage can be prevented (Kashiwada & Takagi, 1991; Inoue & Shimono, 1992; Inoue & others, 1993; Katoh, 1993; Onoe, 1994). There are many commercially available adhesive resin systems with different components and different degrees of adhesiveness to teeth (Chigira, Itoh & Wakumoto, 1991; Dickinson & others, 1991). There are, however, few reports concerning the relationship between the adhesiveness to teeth in vivo and histological pulpal reactions when the adhesive resins are used as direct pulp capping materials.

In the present study, the authors selected four adhesive resins with different chemical components. Pulpal responses to direct pulp capping with each adhesive resin were examined histopathologically. Moreover, the adhesiveness of each resin system in vivo was evaluated by observing gap formation between the resin and cavity wall and the correlation between the leakage and histopathological pulpal results.

Table 1. Adhesive Resin Systems Used

Adhesive Resin System	Batch #	Manufacturer
Superbond C&B system		Sun Medical Co
10-3 solution	30202	Kyoto, Japan
PMMA powder	21203	
Liquid (4-META/MMA)	30301	
Catalyst (TBB)	30311	
Clearfil Liner Bond system		Kuraray Co
CA agent	1127	Osaka, Japan
Clearfil Photobond	279	
Protect Liner	0018	
Tokuso Light Bond sytem		Tokuyama Co
Etching agent	941	Yamaguchi, Japan
Light Bond	067	
Palfique Estelite A3	283	
One All system*		3M Dental Products
Multi-Purpose etchant	2BJ	St Paul, MN 55144
Multi-Purpose adhesive	2AP	
Restorative Z100 A3	2BA	

*Scotchbond Multi-Purpose in the United States

METHODS AND MATERIALS

Table 1 shows the materials used. Twenty wistar rats weighing about 250 g were placed under general anesthesia induced by 10% Nembutal (Dinabot Co, Osaka, Japan). These rats were used throughout the procedures. Four teeth per rat, for a total of 80 teeth, were used. Five teeth were selected randomly for use with each adhesive resin at indicated time intervals. Cavities in the occlusal surfaces of maxillary first and second molars were prepared with a 1/2 round tungsten carbide bur at high speed under copious water spray, until the vital pulp was exposed. The depth of cavities was about 0.8-1.0 mm and the diameter of exposed pulp was about 0.5-0.7 mm. The exposed pulp surface was treated with 10% NaOCl for hemostasis and sterilization for less than 1 minute. After rinsing with physiological saline and drying, the cavities were filled with one of four kinds of adhesive resins according to the following methods.

1) Superbond C&B system: A mixture of MMA liquid containing 4-META, PMMA powder, and Catalyst (partially oxidized TBB) was directly applied to the exposed pulp surface. After the resin had cured, the cavity preparation was conditioned with 10-3 solution (10% citric acid, 3%, $FeCl_3$ aqueous solution) for 20 seconds, rinsed, and dried. The preparation was then bulk filled with a mixture of MMA liquid, PMMA powder, and Catalyst.

2) Clearfil Liner Bond system: Clearfil Photobond containing MDP (methacryloyloxydecyl dihydrogen phosphate) and HEMA (hydroxyethyl methacrylate) was directly applied to the exposed pulp and photocured for 20 seconds. The cavity was then conditioned with CA agent (10% citric acid, 20% $CaCl_2$ aqueous solution) for 20 seconds, then rinsed and dried. Clearfil Photobond was applied to the preparation and photocured for 20 seconds. The cavity preparation was then bulk filled with the composite Protect Liner and photocured for 20 seconds.

3) Tokuso Light Bond system: The general procedure was the same as that used in the Clearfil Liner Bond system. Light Bond containing MAC-10 (11-methacryloxy-1, 1-undecanedicarboxylic acid) was applied directly onto the pulp and photocured for 20 seconds. The cavity preparation was then etched with phosphoric acid gel for 20 seconds, rinsed and dried. After the application and photocuring of Light Bond into the cavity, it was bulk filled with Palfique

Table 2. Criteria of the Formulation of Microleakage

Criteria	Degree of Microleakage
0	No microleakage
1	Less than 1/4 the distance between resin and tooth from cavosurface margin to pulp
2	Between 1/4 and 1/2 the distance between resin and tooth from cavosurface margin to pulp
3	Between 1/2 and 3/4 the distance between resin and tooth from cavosurface margin to pulp
4	More than 3/4 the distance between resin and tooth from cavosurface margin to pulp

Estelite A3 and photocured for 20 seconds.

4) One All system (Scotchbond Multi-Purpose): The general procedure was also the same as that used in the Clearfil Liner Bond system. Multi-Purpose Adhesive, containing BIS-GMA and HEMA, was applied directly onto the pulp surface and photopolymerized for 20 seconds. The cavity was etched with Multi-Purpose Etchant (10% maleic acid gel) for 20 seconds. After rinsing and drying, Multi-Purpose Adhesive was applied to the cavity and polymerized by photocuring for 20 seconds. Restorative Z100 (shade A3) was placed as a bulk in the cavity and photocured for 20 seconds.

The animals, while under general anesthesia, were sacrificed at 3, 7, 30, or 90 days with 10% Nembutal. Specimens were fixed with 10% neutralized buffered formalin for 3 days. The specimens were then embedded in paraffin, and serial sections 5 microns thick were cut on a microtome and stained with hematoxylin-eosin. Histopathological investigations were carried out by observation under a light microscope (X4 ~ X250). The parameters observed histopathologically were as follows: capillary dilatation, hyperemia, congestion, bleeding, inflammatory cell infiltration, reticular atrophy, vacuolar degeneration, secondary dentin calcification, and necrosis. The intensities of these histopathological responses were classified into four grades: none, slight, moderate, and severe, according to the reported criteria (Mjör & Tronstad, 1972; Katoh, 1993). Statistical analysis was carried out using the chi-square test between the four time intervals (3, 7, 30, and 90 days) within each adhesive resin system and among the adhesive resin systems at the same time intervals.

The formation of leakage between the resin and cavity wall was observed. After 7 days, the animals were sacrificed, the teeth removed, embedded in acrylic resin, and cross-sectioned perpendicular to the resin-cavity wall interface. They were then polished with a 1000-grit stone, then successively with special soft disks using diamond suspensions of 6 µm-, 1 µm-, and 0.25 µm-grit size (Struers, Copenhagen, Denmark). The samples were then cleaned ultrasonically for 3 minutes to remove the polishing debris and paste. The formation of

Table 3. Results of the Histopathological Findings

Material	Time Intervals (days)	capillary dilatation, hyperemia, congestion	bleeding	inflammatory cell infiltration	reticular atrophy	vacuolar degeneration	secondary dentin calcification	necrosis
		- ± + ++	- ± + ++	- ± + ++	- ± + ++	- ± + ++	- ± + ++	- ± + ++
Superbond C&B	3	1 4 0 0	5 0 0 0	0 1 4 0	5 0 0 0	5 0 0 0	5 0 0 0	5 0 0 0
	7	1 4 0 0	5 0 0 0	0 5 0 0	5 0 0 0	5 0 0 0	5 0 0 0	5 0 0 0
	30	5 0 0 0	5 0 0 0	5 0 0 0	5 0 0 0	5 0 0 0	0 5 0 0	5 0 0 0
	90	5 0 0 0	5 0 0 0	5 0 0 0	5 0 0 0	5 0 0 0	0 1 4 0	5 0 0 0
Clearfil Liner Bond	3	0 1 4 0	5 0 0 0	0 1 4 0	5 0 0 0	5 0 0 0	5 0 0 0	5 0 0 0
	7	1 4 1 0	5 0 0 0	0 5 0 0	2 3 0 0	5 0 0 0	5 0 0 0	5 0 0 0
	30	0 5 0 0	5 0 0 0	0 5 0 0	5 0 0 0	1 4 0 0	5 0 0 0	2 3 0 0
	90	0 5 0 0	5 0 0 0	0 5 0 0	5 0 0 0	0 5 0 0	1 4 0 0	1 4 0 0
Tokuso Light Bond	3	0 0 5 0	0 5 0 0	0 0 5 0	0 1 4 0	0 5 0 0	5 0 0 0	1 4 0 0
	7	0 0 5 0	0 5 0 0	0 0 5 0	0 0 5 0	0 1 4 0	5 0 0 0	0 1 4 0
	30	0 0 5 0	0 5 0 0	0 0 5 0	0 0 5 0	0 1 4 0	5 0 0 0	0 0 0 5
	90	0 0 5 0	0 5 0 0	0 0 5 0	0 0 5 0	0 0 0 5	5 0 0 0	0 0 0 5
One All	3	0 0 1 4	0 5 0 0	0 0 5 0	0 4 1 0	0 5 0 0	5 0 0 0	5 0 0 0
	7	0 0 5 0	0 1 4 0	0 0 5 0	0 5 0 0	0 5 0 0	5 0 0 0	0 1 4 0
	30	0 0 5 0	0 1 4 0	0 0 5 0	0 5 0 0	0 1 4 0	5 0 0 0	0 0 5 0
	90	0 0 5 0	0 5 0 0	0 0 1 4	0 1 4 0	0 1 4 0	5 0 0 0	0 0 0 5

- = none; ± = slight; + = moderate; ++ = severe; numbers refer to criteria in Table 2.

microleakage was observed using a polarizing microscope and evaluated using criteria listed in Table 2. Three samples were evaluated for each adhesive resin.

RESULTS

The histopathological findings of direct pulp capping using the different adhesive resins are summarized in Table 3. Figures 1-5 show representative histopathological photographs.

There were no severe pulp responses to direct pulp capping with Superbond C&B. Slight capillary dilatation, hyperemia, congestion, and inflammatory cell infiltration were observed after 3 days as shown in Figure 1. However, these reactions were significantly diminished after 30 days ($P < 0.01$), and the formation of secondary dentin was observed beneath the exposed pulp surface (Figure 2). There was no necrosis of the pulp with the use of Superbond C&B.

Most specimens with Clearfil Liner Bond system showed slight pulpal responses. The appearance of capillary dilatation, hyperemia, and congestion was significantly reduced after 30 days ($P < 0.01$); however, slight inflammatory cell infiltration was still present after 90 days. These reactions did not completely diminish. Slight vacuolar degeneration was observed after 30 and 90 days. After 90 days, slight necrosis and secondary dentin formation were found to be significant, as shown in Figure 3.

The findings of direct pulp capping using the Tokuso Light Bond system were very severe. Seven days after application, capillary dilatation, hyperemia, congestion, bleeding, and inflammatory cell infiltration were observed in the deeper pulp, and necrosis was seen in the superficial pulp. The inflammatory cell response was still found after 90 days, with no observable diminishing of severe pulpal responses (Figure 4). There were no statistically significant differences among the four time intervals. Reticular atrophy and vacuolar degeneration spread into the whole of the coronal pulp, and no formation of secondary dentin was observed after 90 days.

Histopathological findings of the One All system were similar to those of the Tokuso Light Bond system, and severe pulpal responses were found in the whole of the pulp after 90 days (Figure 5). Inflammatory cell infiltration and reticular atrophy significantly increased at the 90-day evaluation period. Vacuolar degeneration also significantly

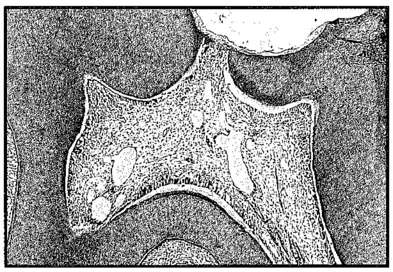

Figure 1. *Direct pulp capping with the Superbond C&B system after 3 days. Very slight capillary dilatation, hyperemia, congestion, and inflammatory cell infiltration were observed. (magnification X20)*

Figure 2. *Direct pulp capping with the Superbond C&B system after 30 days. There were no severe reactions, and secondary dentin formation was observed. (magnification X25)*

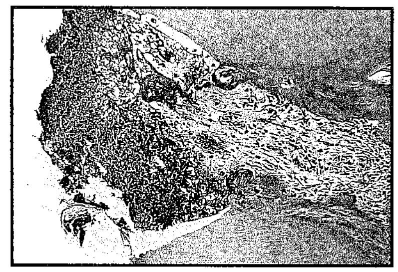

Figure 3. *Direct pulp capping with the Clearfil Liner Bond system after 90 days. Slight vacuolar degeneration, capillary dilatation, hyperemia, congestion, inflammatory cell infiltration, necrosis, and formation of secondary dentin were observed. (magnification X16.5)*

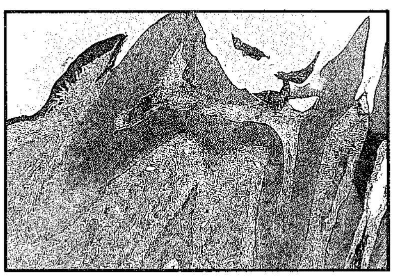

Figure 4. *Direct pulp capping with the Tokuso Light Bond system after 90 days. Very severe capillary dilatation, hyperemia, congestion, inflammatory cell infiltration, necrosis, spreading of reticular atrophy, and vacuolar degeneration were observed. (magnification X4)*

Figure 5. *Direct pulp capping with the One All system after 90 days. Very severe pulpal responses were observed throughout the pulp. (magnification X8)*

Table 4. Results of Formation of Microleakage

Material	Average of Microleakage*
Superbond C&B	0
Clearfil Liner Bond	2/3
Tokuso Light Bond	4
One All	4

*Numbers refer to criteria in Table 2.

increased after 30- and 90-day intervals ($P < 0.01$).

Although there were no significant differences among the four kinds of adhesive resin in inflammatory cell infiltration after 3 days, significant differences were observed after 7 days among the Superbond C&B system, Tokuso Light Bond system, and One All system. Inflammatory cell infiltration with the Clearfil Liner Bond system was significantly different from that with the Superbond C&B system after 30 days.

The results of the evaluation of microleakage are listed in Table 4, and Figures 6-8 illustrate the microleakage pattern between the filled resin and cavity wall. There was no microleakage with the Superbond C&B system (Figure 6), and very little was observed with the Clearfil Liner Bond system (Figure 7). The Tokuso Light Bond system showed a wide area of microleakage formation, as shown in Figure 8, as did the One All system. There are significant differences between the results by the Superbond C&B, and Clearfil Liner Bond system, compared to the Tokuso Light Bond and One All systems.

DISCUSSION

In the present study, four kinds of adhesive resins with different chemical compounds were directly applied onto the exposed pulp of rats, and histopathological responses of the pulp were studied. Gap formation in vivo was also examined.

Microleakage formation correlated with the histopathological responses of the exposed pulp. The Superbond C&B system showed little inflammatory cell responses in the exposed pulp, and no formation of microleakage between the adhesive resin and tooth substrate. Histopathological results with the Clearfil Liner Bond system were moderate but were inferior to those with the Superbond system due to slight formation of microleakage. Bond strengths of these resins have been reported (Chigira & others, 1991; Dickinson & others, 1991), but high bond strength does not always produce complete marginal sealing between the resin and tooth structure. The marginal leakage formed by the Tokuso Light Bond and One All systems, and the severe pulpal responses with these two systems, appeared to originate from bacterial invasion through leakage between the restorative resin and the cavity wall.

HEMA was used as a component in the Photobond of Clearfil Liner Bond system and Multi-Purpose Adhesive of the One All system. Histopathological findings of the Clearfil Liner Bond system were different from those of the One All system. The major contribution to pulpal irritation appears to be the existence of a gap between the resin and cavity wall in these specimens.

Cox and others (1987), Cox (1992), and Snuggs and others (1993) reported a correlation between material biocompatibility and pulp condition only when microleakage and bacterial infection were prevented within the restoration/resin interface. They observed that the exposed pulp possessed an inherent healing capacity for cellular reorganization and dentinal bridge formation when a proper biological seal was provided and maintained against the leakage of oral contaminants. The excellent histopathological results obtained with direct pulp capping using Superbond C&B were presumably attributed to its high adhesiveness to teeth forming a complete marginal seal.

Hemostasis of the exposed pulp is very important for the success of direct pulp capping with adhesive

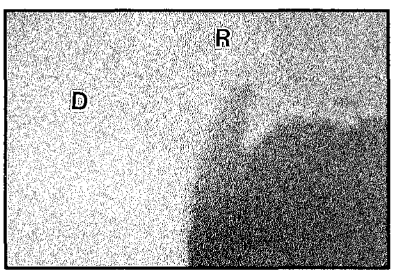

Figure 6. *No microleakage formation was observed with the Superbond C&B system. R = resin; D = dentin. (magnification X100)*

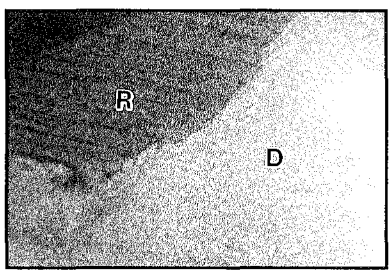

Figure 7. *A little microleakage formation was observed with the Clearfil Liner Bond system. R = resin; D= dentin. (magnification X100)*

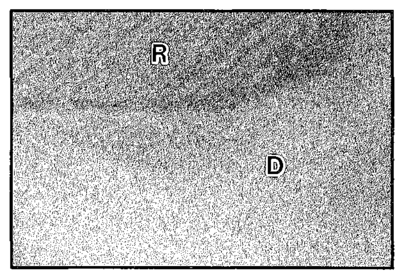

Figure 8. *Microleakage formation was observed with the Tokuso Light Bond system. R = resin; D = dentin. (magnification X100)*

resin systems (Inokoshi & others, 1990). Katoh (1993) and Onoe (1994) reported that chemical treatment with 10% NaOCl and 3% H_2O_2 is useful for hemostasis. In this study, we used only 10% NaOCl for hemostasis because of the small amount of bleeding; without NaOCl treatment, evaluation of the histopathological findings would be very difficult due to the large amount of pulpal bleeding. It is impossible to state that the baseline status of each pulp treated with NaOCl would be similar. Further study concerning the influence of NaOCl treatment on the pulp is necessary.

Direct pulp capping with adhesive resin is clinically useful if a complete marginal seal can be obtained. However, the choice of the adhesive resin system is important to the success of the direct pulp capping because of the differences in adhesiveness to the tooth, and no accepted clinical protocol for using adhesive resin has yet been established. Although we only applied the bonding agents to the exposed pulp, some investigators have applied acid etching to the pulp (Kashiwada & Takagi, 1991; Katoh, 1993). The histopathological influence on pulpal irritation by the different clinic protocols needs further study.

CONCLUSIONS

Direct pulp capping using various adhesive resins was studied histopathologically, with the following results:

1. The Superbond C&B system induced slight capillary dilatation, hyperemia, congestion, and inflammatory cell infiltration only at 3 days after the operation. The formation of secondary dentin was observed at the 3-day evaluation period.
2. The Clearfil Liner Bond system showed slight capillary dilatation, hyperemia, congestion, and inflammatory cell infiltration at all stages after the operation. Slight necrosis and formation of secondary dentin were observed 90 days after the "capping" procedure.
3. Tokuso Light Bond and One All system showed severe pulpal reactions at all stages after the operation. No secondary dentin formation was observed at any of the evaluation periods for these two systems.
4. There was a correlation between the formation of microleakage and pulpal reaction. Severe pulpal irritation occurred when the greatest microleakage was observed between the applied resin and cavity wall.
5. Further in vivo study evaluating the clinical use of adhesive resins for pulp capping is indicated.

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Microleakage of New Dentin Bonding Systems Using Human and Bovine Teeth

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Clinical Relevance
Results suggest that bovine teeth can be used in place of human teeth for in vitro microleakage studies.

SUMMARY

The objective of this study was twofold: to evaluate the microleakage behavior of three dentin bonding systems and to determine if bovine teeth are comparable substrates to human teeth when studying the microleakage of various materials. The materials evaluated were Scotchbond Multi-Purpose Adhesive, Prisma Universal Bond 3, and All-Bond 2. All three bonding systems were used in combination with Prisma APH hybrid composite for comparison of microleakage behavior. Sixty class 5 preparations were cut at the cementoenamel junction for groups containing 30 human and 30 bovine teeth. A 1 mm 45° bevel was placed at the enamel margin. Teeth were grouped according to the dentin bonding system used and then restored according to the manufacturer's directions. After restoration, the teeth from each group were stored in distilled water at 37 °C for 3 days. The teeth were then thermocycled between 4 °C and 58 °C for 100 cycles and returned to distilled water at 37 °C for an additional 4 days. The teeth were then sealed with nail polish up to 1 mm from the margins of the restoration and placed in ^{45}Ca isotope for 2 hours. The teeth were then sectioned and placed on x-ray film to produce autoradiographs. Microleakage was evaluated for the enamel and dentin margins separately using the following scale: 0 = no leakage, 1 = penetration of isotope to less than 1/2 the distance to the axial wall, 2 = penetration of isotope greater than 1/2 of the distance to the axial wall but short of the axial wall, and 3 = penetration of isotope to the axial wall or beyond. The materials were compared to each other using the Mann-Whitney U and Kruskal-Wallis tests. The gingival margins were compared to the incisal margins for all materials. No statistically significant differences in microleakage were revealed between the incisal and gingival location for human substrates, but there was statistically significant greater gingival microleakage for bovine substrates. All-Bond 2 leaked significantly more than Scotchbond Multi-Purpose for human substrates at the incisal margin. All-Bond 2 had significantly more microleakage than Prisma Universal Bond 3 at both dentin and enamel margins for the bovine substrate. There were no statistically significant differences in microleakage among the bonding systems for the human substrate. No statistically significant differences between the microleakage behavior of human and bovine substrates were

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found. These results support the use of bovine teeth for in vitro microleakage studies.

INTRODUCTION

Since the advent of composite materials in dentistry, continual improvement has been made in their properties. Microleakage, however, still occupies a major focus of researchers trying to improve the longevity of composite restorations. Manufacturers have developed bonding agents in an effort to control leakage at the tooth-restoration interface by optimizing bonding through improved resin technology. Scotchbond Multi-Purpose Adhesive contains a mixture of hydroxyethylmethacrylate (HEMA) and BIS-GMA, and the primer component is an aqueous solution of HEMA and Vitrebond copolymer (3M) (Fitchie & others, 1994). L D Caulk/Dentsply has recently developed Prisma Universal Bond 3, a combination of dipentaerythritol pentacrylate phosphoric acid ester (PENTA), HEMA, ethanol, triethylene glycol dimethacrylate (TEGDMA), and UDMA (Fitchie & others, 1994). Bisco has also introduced All-Bond 2, which is comprised of HEMA, BIS-GMA, N-tolyglycine-glycidyl methacrylate (NTG-GMA), acetone, and biphenyl dimethacrylate (BPDM) (Eliades, 1992).

Current dentin bonding systems remove, penetrate, or alter the smear layer. These systems incorporate hydrophilic monomers, which penetrate the remaining dentin. Micromechanical retention is achieved through resin tags into the dentinal tubules and resin impregnation of collagen fibers and demineralized intertubular dentin. This resin-modified zone has been called a "hybrid layer" and provides a surface that will copolymerize with the resin adhesive component (Sturdevant & others, 1995). The objective of this study was twofold: to evaluate the microleakage behavior of these three dentin bonding systems and to determine if bovine teeth are comparable substrates to human teeth when studying the microleakage of various materials.

Bovine and human teeth were compared because of the increased popularity of using bovine teeth for microleakage and bond strength studies (Puckett & others, 1992; Nakabayashi, 1992; Tsai & others, 1990; Saunders, 1988). Human teeth are morphologically and histologically similar to other mammalian teeth (Weichert & Presch, 1975), but size and availability make bovine incisors preferable for research. The use of bovine teeth in dental research is largely due to a study by Nakamichi, Iwaku, and Fusayama (1983), who reported similar resin bond strengths for enamel and superficial dentin of bovine and human teeth. They also examined morphological differences between bovine and human enamel and dentin. Unetched bovine enamel appeared slightly rougher. A different acid etch pattern was noted between the arcade-shaped human enamel and the small oval-shaped bovine enamel. Etched and unetched superficial dentins were morphologically similar where both presented occluded dentinal tubules that could be opened by acid-etching.

Rueggeberg (1991) suggested that the current literature was insufficient to compare the two substrates. Sydney-Zax, Mayer, and Deutsch (1991) reported that unerupted mature bovine enamel was slightly higher in carbonate concentration than human enamel, indicating that bovine teeth could be more susceptible to an acid attack due to the variations in the hydroxyapatite lattice. Saunders (1988) determined that the shear bond strengths of four

Table 1. Materials

Product	Manufacturer	Etch	Primer	Adhesive
Scotchbond Multi-Purpose Adhesive	3M Dental Products, St Paul, MN 55144	10% maleic acid (in enamel and dentin)	HEMA/polyalkenoic acid, MMA, copolymer	BIS-GMA, HEMA
Prisma Universal Bond 3	L D Caulk/Dentsply, Milford, DE 19963	(not included in kit) 32% phosphoric acid (enamel only)	ethanol, HEMA, PENTA	PENTA, UDMA, TEGDMA, glutaraldehyde
All-Bond 2	Bisco Inc, Itasca, IL 60143	32% phosphoric acid (enamel only)	NTG-GMA, BPDM, acetone	BIS-GMA, HEMA
Prisma APH hybrid composite	L D Caulk/Dentsply	COMPONENTS: urethane-modified BIS-GMA, barium glass, fumed silica, photoinitiators, color pigments		

dentin bonding agents were not significantly different between bovine and human dentin.

In a study by Tagami, Tao, and Pashley (1990) an increase in permeability with increased depth was noted in both human and bovine dentin. Bovine incisor dentin possessed larger dentinal tubules and increased microporosity, which was similar to human molar root dentin. The results of an evaluation of surface free energies of the two substrates by Brown, Puckett, and Givan (1992) postulated that bovine tooth structure may provide a more severe adhesion test for dentinal bonding agents than the human substrate.

METHODS AND MATERIALS

The bonding agents described in Table 1 were evaluated in vitro, using bovine and human teeth with the hybrid composite resin Prisma APH. Thirty freshly extracted bovine and 30 freshly extracted human teeth were selected, and all teeth were stripped of calculus and debris using a scalpel. The teeth were then cleaned with a slurry of pumice and water and stored in refrigerated distilled water until preparation. Traditional class 5 preparations were prepared on the facial surface of the study teeth to the following dimensions: 2 mm axially, 3 mm mesiodistally, and 2 mm incisogingivally. The incisal margin was placed on enamel and the gingival margin was located apical to the cementoenamel junction. A 1 mm, 45° bevel was placed at the incisal margin.

Table 2. Adhesive Procedures

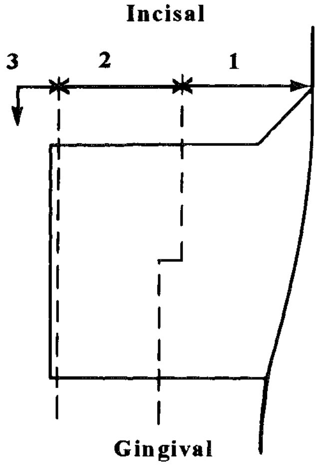
All-Bond 2	Universal Bond 3	Scotchbond Multi-Purpose
etched enamel only for 20 seconds with 32% phosphoric acid	etched enamel only for 20 seconds with 32% phosphoric acid	enamel and dentin etched with 10% maleic acid for 15 seconds
rinsed	rinsed	rinsed
air dried without desiccation	air dried without desiccation	teeth kept moist under wet paper towel
five coats of A and B primer mixture	one coat of primer applied and dried with air syringe	one coat of primer applied and dried with air syringe
adhesive applied with brush, gently spread with air syringe	adhesive applied with brush, gently spread with air syringe and light cured for 20 seconds	adhesive applied with brush, gently spread with air syringe and light cured for 20 seconds

After preparation, the teeth were covered with a wet paper towel to prevent dessication before restoration with the appropriate bonding system. The following procedures are summarized in Table 2. For the All-Bond 2 and Prisma Universal Bond 3 groups, the enamel was etched with 32% phosphoric acid for 20 seconds without agitation, then rinsed with water and gently air dried without dessication. Although one of the manufacturer's directions for All-Bond 2 does incorporate a dentin etch, the conservative, enamel-only etch, which is also advocated, was used for both All-Bond 2 and Prisma Universal Bond 3. Phosphoric acid was intentionally not used to etch dentin in this study, because many authors have found that phosphoric acid as a conditioning agent was too destructive, since it removed the smear layer, opened and widened (funnelled) dentinal tubules, and increased the severity of the pulpal responses to materials placed subsequently (Stanley, 1992).

Ten percent maleic acid was used as the etchant to condition both the enamel and dentin for the Scotchbond Multi-Purpose groups as stated in the manufacturer's directions. All conditioned or etched teeth were kept slightly moist under a wet paper towel until the priming and adhesive steps were performed.

For the All-Bond 2 groups, the A and B primer mixture was applied in five consecutive coats with a brush until a glossy dentin surface was observed. For the Scotchbond Multi-Purpose and Prisma Universal Bond 3 groups one coat of primer was applied to enamel and dentin the recommended time and dried gently with an air syringe. The appropriate adhesive for each system was then applied with a brush to the primed enamel and dentin surfaces and spread gently with an air syringe to obtain an even layer. The adhesive layer was light cured for 20 seconds prior to composite placement.

The hybrid resin Prisma APH was placed with a bulk fill technique (Puckett & others, 1992; Schwartz, Anderson & Pelleu, 1990), overfilled slightly, and cured for 60 seconds. All restorations were finished and polished with the Sof-Lex system (3M) to the respective margins. Teeth were stored in 37 °C distilled water for 12 hours, then thermocycled between 4 °C and 58 °C for 100 cycles. The cycles were for 1 minute each with a 10-second transfer time. Following cycling, the teeth were stored in distilled water at 37 °C for an additional 4 days. The samples were then sealed with fingernail polish up to 1 mm from the restoration margins. Excessively open root apices were sealed with utility wax and two coats of nail polish. The samples were then placed in ^{45}Ca solution for 2 hours. The teeth were sectioned longitudinally on a wet aluminum oxide wheel, scrubbed with detergent, and allowed to air



0 = no evidence of isotope penetration at the interface of tooth and restoration; 1 = isotope penetration up to 1/2 the distance to the axial wall; 2 = isotope penetration beyond 1/2 the distance to the axial wall but short of the axial wall; 3 = isotope penetration to the axial wall.

dry prior to autoradiography (Hembree & Andrews, 1978).

The microleakage of the samples was evaluated, as described in the figure, using the following criteria: 0 = no evidence of isotope penetration at the interface of tooth and restoration; 1 = isotope penetration up to 1/2 the distance to the axial wall; 2 = isotope penetration beyond 1/2 the distance to the axial wall but short of the axial wall; and 3 = isotope penetration to the axial wall or beyond.

Microleakage of the enamel and of the dentin margins were evaluated separately. Statistical differences within groups were determined using the Kruskal-Wallis test, and paired comparisons were made using the Mann-Whitney U Test.

RESULTS

The microleakage scores for the three bonding systems for the human and bovine substrates are given in Tables 3 and 4 respectively. To simplify discussion, analysis of the results is separated into sections that compare the bonding agents for each substrate separately and a section that compares the substrates.

Human Substrate

When the bonding agents were compared for the incisal margin, the rank order of decreasing leakage was All-Bond 2 > Universal Bond 3 > Scotchbond Multi-Purpose, and the difference between All-Bond 2 and Scotchbond Multi-Purpose was significant ($P = 0.047$). When the materials were compared for the gingival margins, the order changed, with Scotchbond Multi-Purpose > Universal Bond 3 > All-Bond 2, but the differences were not significant ($P > 0.05$). Comparison of the gingival margins to the incisal margins for the materials grouped and individually revealed no significant differences ($P > 0.05$). Less leakage was found at the incisal margin, but it was not statistically significant ($P = 0.486$).

Bovine Substrate

When the materials were compared for the incisal margin only, the rank order of materials with decreasing leakage was All-Bond 2 > Scotchbond Multi-Purpose > Universal Bond 3. Paired comparison reveals that All-Bond 2 leaked significantly more than

Table 3. Bovine Substrate Microleakage Scores

	0	1	2	3
incisal	16	10	1	2
gingival	8	9	6	6
AB2 inc	3	5	0	2
UB3 inc	7	3	0	0
SBMP inc	6	2	1	0*
AB2 gin	1	3	2	4
UB3 gin	5	3	2	0
SBMP gin	2	3	2	2*

*Lost sample; AB2 = All-Bond 2; UB3 = Universal Bond 3; SBMP = Scotchbond Multi-Purpose; inc = incisal; gin = gingival.

Table 4. Human Substrate Microleakage Scores

	0	1	2	3
incisal	11	12	4	2
gingival	10	8	6	5
AB2 inc	2	4	3	1
UB3 inc	3	5	0	1*
SBMP inc	6	3	1	0
AB2 gin	4	3	1	2
UB3 gin	2	3	3	1*
SBMP gin	4	2	2	2

*Lost sample; AB2 = All-Bond 2; UB3 = Universal Bond 3; SBMP = Scotchbond Multi-Purpose; inc = incisal; gin = gingival.

Universal Bond 3 (P = 0.051). Comparison of the materials at the gingival margin gave the same order: All-Bond 2 > Scotchbond Multi-Purpose > Universal Bond 3, and All-Bond 2 again leaked significantly more than Universal Bond 3 (P = 0.018). When the gingival margins were compared to the incisal margins for all materials, the gingival margins leaked significantly more than the incisal margins (P = 0.009). When the margins were compared for individual materials, Scotchbond Multi-Purpose leaked significantly more at the gingival margin (P = 0.044).

Substrate Comparison

Materials were compared independently for effects of the substrate on microleakage behavior. For All-Bond 2 the human incisal margin leaked more than the bovine incisal margin, and the human gingival margin leaked less than the bovine incisal margin; however, the differences were not significant: P=0.528 and P=0.123 respectively. Scotchbond Multi-Purpose followed the same trend as All-Bond 2 with more leakage found at the human incisal compared to the bovine incisal, and the human gingival showed less leakage than the bovine gingival. Again the differences were not significant with P=0.683 and 0.610 for the incisal and gingival comparisons. The Universal Bond 3 bonding agent showed more leakage at the human gingival and incisal margins than the bovine margins, but the difference was not significant, with P = 0.093 and P = 0.153 respectively. When the materials were grouped and compared there was no significant effect of the substrate (P > 0.05) on microleakage at the incisal and gingival margin, but bovine incisal margins leaked less and bovine gingival margins leaked more than the respective human margins. When the materials were compared using both substrates, the rank for the incisal margin was All-Bond 2 > Universal Bond 3 > Scotchbond Multi-Purpose, and the difference between All-Bond 2 and Scotchbond Multi-Purpose was significant (P = 0.037). The rank order for the gingival margin was All-Bond 2 > Scotchbond Multi-Purpose > Universal Bond 3, but the differences were not statistically different. When just the substrates are compared for all margins and materials, there were no significant differences (P = 0.71 5).

DISCUSSION

Microleakage has been suggested to be the result of polymerization shrinkage and the thermal expansion coefficient differences between tooth structure and the restorative material. The polymerization shrinkage and expansion coefficient differences can exert significant forces at the restorative material/tooth interface, resulting in bond failure and gap formation. Clinical implications of this bond failure and gap formation can be postinsertion sensitivity, marginal staining, recurrent decay and/or possible loss of the restoration (Phillips, 1982). The analysis of the data from this study revealed that bonding to dentin is variable. Although some materials are bonding better, more improvement is needed to completely seal gingival margins.

All-Bond 2 may have leaked less in this study if the dentin had been etched with phosphoric acid. We did not do this for two reasons. The manufacturer's directions for All-Bond 2 state that the bonding system can be used with or without etching the dentin. Since we did not etch the dentin with phosphoric acid for Universal Bond 3, we chose not to etch the dentin for All-Bond 2. We did etch the dentin with maleic acid for the Scotchbond Multi-Purpose samples. However, this is in accordance with the manufacturer's directions.

It is suggested that during polymerization, the composite material will contract toward the incisal margin because of the stronger adhesive bond to acid-etched enamel, resulting in a gap at the gingival margin (Sidhu & Henderson, 1992; Davidson, deGee & Feilzer, 1984). The results of this study suggest that none of the bonding agents tested was consistently capable of resisting the forces exerted during polymerization and/or thermocycling, especially at the gingival margin. However, these results are from in vitro data and should not be the only criteria used to predict clinical performance.

CONCLUSIONS

1. All-Bond 2 leaked significantly more than Scotchbond Multi-Purpose for human substrates at the incisal margin.
2. All-Bond 2 leaked significantly more than Prisma Universal Bond 3 at both margins for the bovine substrate.
3. Gingival margins leaked significantly more than incisal margins when bovine teeth were evaluated.
4. No statistically significant differences between the microleakage behavior of human and bovine substrates were found.
5. Results suggest that bovine teeth can be used in lieu of human teeth for in vitro microleakage studies.

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Shear Bond Strength of Resin-mediated Amalgam-Dentin Attachment after Cyclic Loading

D McCOMB • J BROWN • M FORMAN

Clinical Relevance
Occlusal function may significantly reduce tooth reinforcement with bonded amalgam restorations.

SUMMARY

Several in vitro studies have suggested that a resin-mediated attachment mechanism can provide tooth reinforcement with silver amalgam restorations. This study investigated the ability of this attachment to withstand simulated occlusal function. Forty bovine incisors were divided into four groups. Prepared tooth surfaces were treated with a dentin bonding system (All-Bond 2) followed by amalgam (Tytin) condensation into a split mold. Samples were tested for shear bond strength after no cyclic loading or after 1000 and 5000 cycles with a weight of 700 grams (1.5 lb) at one strike per second. Mode of failure was assessed by microscopic investigation of fracture sites. The 24-hour shear bond strength (7.11 ± 1.93 MPa) of Tytin spherical amalgam to dentin was progressively reduced after cyclic loading. Bond failure invariably occurred at the interface between the adhesive resin and amalgam. It was concluded that occlusal function may significantly reduce tooth reinforcement with bonded amalgam restorations.

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INTRODUCTION

It is well recognized that cavity preparation weakens teeth (Larson, Douglas & Geistfeld, 1981) and increases their susceptibility to fracture during function (Cavel, Kelsey & Blankenau, 1985; Eakle, Maxwell & Braly, 1986), particularly when large approximo-occlusal preparations are present (Granath & Svensson, 1991). Silver amalgam provides a condensable, carvable, and clinically durable restorative material; however, a significant disadvantage is the lack of attachment to remaining tooth structure. Bonded composite resin restorations can increase the fracture resistance of teeth (Eakle, 1986), but posterior composites are associated clinically with a higher incidence of defective restorations (Hewlett & others, 1993). In recent years, a technique of resin-mediated attachment of silver amalgam to tooth structure has been developed, in an attempt to utilize proven resin bonding techniques to provide tooth reinforcement with dental amalgam. Such a "bonded amalgam" technique has been shown to increase the fracture resistance of silver-amalgam-restored teeth in vitro (Eakle, Staninec & Lacy, 1992; Ianzano, Mastrodomenico & Gwinnett, 1993).

Nearly all studies investigating resin-mediated amalgam bond strength and fracture strength of restored teeth utilize monotonic static loading. However, teeth and restorations undergo dynamic, repetitive loading during oral function, and the bonded interface is subject to fatigue failure. The clinical success of resin-mediated amalgam to tooth attachment will therefore depend on the ability of this interface to resist fatigue.

The objective of this study was to assess by shear bond strength measurements after cyclic mechanical loading, the ability of this attachment mechanism to withstand simulated occlusal function, and to examine the mode of failure by scanning election microscopy.

METHODS AND MATERIALS

Forty bovine maxillary incisors were equally divided into four treatment groups (table). A standardized mold filled with autopolymerizing methacrylate resin was used to mount the teeth so that the facial surfaces were elevated above the base. The teeth were then mounted in a positioning jig and horizontal dentin or enamel surfaces prepared by sequential use of wet 180-, 320-, and 600-grit rotating silicon carbide paper disks. Samples were stored in 37 °C distilled water.

Immediately prior to use prepared surfaces were refreshed lightly with wet 600-grit silicon carbide paper to remove possible bacterial debris, thoroughly washed, and dried with compressed air. Enamel surfaces were etched and dentin surfaces were conditioned and primed according to manufacturer's instructions (All-Bond 2, Bisco Inc, Itasca, IL 60143). Dentin surfaces were lightly dried, not visibly moist, prior to priming. Double-sided adhesive tape with a punched hole approximately, but not less than, 4.6 mm in diameter was applied to the undersurface of a split mold teflon tube with an internal diameter of 4.6 mm, held in a rigid two-part casing, and the tube positioned perpendicular onto the prepared tooth surface. The assembly was secured with a clamp, and a thin coat of the autocuring resin was applied to the tooth surface, utilizing one drop of All-Bond 2 bonding resin mixed with one drop of Prebond Resin (Bisco). Triturated amalgam (Tytin, Kerr Mfg Co, Glendora, CA 91740) was immediately condensed into the mold onto the unset resin surface. The supporting jig was removed after 15-20 minutes and the unmolded samples stored in 37 °C distilled water for 24 hours prior to testing.

Group 1 and 2 samples (enamel and dentin) were mounted in a Universal Testing Machine (Instron Corp, Canton, MA 02021) and the amalgam cyclinders subjected to shear bond stress at a cross-head speed of 5 mm/minute to bond failure. Group 3 and 4 samples (dentin) were placed in a custom mechanical cycling machine and cyclic loaded under water at 37 °C with a 700-gram (approximately 1.5 lb) force at one strike per second for 1000 and 5000 cycles respectively. Mechanical loading was delivered by a 7 mm-wide knife edge placed immediately adjacent and parallel to the bonded interface, along a prepared flat plane of the tooth surface, with the amalgam cylinder grasped by the apparatus. Cyclic loaded samples were then immediately shear bond tested, approximately 3 to 4 hours after the start of loading. After debonding, all samples were examined under a low-power (X3) microscope. Representative samples were coated with 15 μm of gold and examined with a Hitachi S-2500 (Hitachi Scientific Instruments, Mountain View, CA 94043) scanning electron microscope.

Shear bond strength data were analyzed using a one-way ANOVA test at a 95% level of significance.

Mean Shear Bond Strengths of Tytin/All-Bond 2 to Tooth Structure

Group	Mechanical Cycle	Substrate	Shear Bond Strength (MPa)	
1	none	enamel	8.29 ± 1.51	(n = 10)
2	none	dentin	7.12 ± 1.93	(n = 10)
3	1000 (1 debond)	dentin	4.37 ± 2.42	(n = 9)
4	5000 (3 debonds)	dentin	2.10 ± 1.68	(n = 7)

Groups joined by a vertical line are not statistically significantly different ($P \leq 0.05$).

RESULTS

The shear bond strength values for the four experimental groups are presented in the table. Moderate-strength shear bond values of resin-mediated attachment of amalgam to enamel (Group 1) and dentin (Group 2) resulted, with no statistically significant difference between them. Mechanical cycling for 1000 and 5000 cycles progressively lowered the shear bond strength to dentin. One Group 3 sample debonded (519 cycles) and three Group 4 samples debonded (49, 1382, 3578 cycles) during mechanical cycling. Statistical analysis by ANOVA of the effect of mechanical cycling on the bond to dentin showed all dentin groups to be statistically significantly different ($P < 0.05$).

For all groups the debonding sites presented similar appearances under low-power magnification. Enamel and dentin bonding surfaces were covered with a layer of resin containing only a few small particles of amalgam. Amalgam surfaces appeared relatively flat with little evidence of surface resin. Typical SEM appearance of the debonded specimens is shown in Figures 1-3.

DISCUSSION

A significant attachment between dentin or enamel and amalgam was achieved that was similar to the higher bond strengths reported in the literature for this technique. Kawakami and Staninec (1991) obtained a value of 6.8 MPa for the same materials used in this study and a range of 3.0 - 7.8 MPa for other recognized dentin adhesives compatible with the technique. Barzilay and Gendusa (1990), using a 4-META-based product, obtained a similar value of 6.7 MPa. This attachment range has been said to be comparable to those achieved with composite resin, but most are considerably lower than recently reported values for dentin bonding with composite (Barkmeier & Cooley, 1992). Titley and others (1993) reported a shear bond strength of 15.5 MPa for composite bonded to dentin with All-Bond.

It is generally accepted that the attachment mechanism is achieved largely by intermingling of the unset adhesive resin and unset amalgam at the time of amalgam insertion, and the micromechanical nature of the attachment was confirmed by SEM in this study. The bond between the adhesive resin and dentin involves micromechanical interdiffusion of resin primers into the lightly demineralized, acid-treated dentin surface (Van Meerbeek & others, 1992). The attachment between the adhesive resin and the hybridized dentin surface or the acid-etched enamel was greater than that between adhesive resin and amalgam, bond failure invariably being seen at this interface, with only small particles of amalgam being retained in the resin. A resinous layer thus remained firmly attached to the dentin or the enamel, and this result is unequivocal in the literature.

The superior resistance to in vitro microleakage of resin-bonded amalgam restorations is undoubtedly due to this resin hybridization with demineralized surface dentin. The use of cavity varnish is the traditional, accepted clinical technique to eliminate initial amalgam microleakage and, provided a careful technique is followed, clinical results are good. In vitro studies have, however, shown the presence of microleakage, particularly at dentin margins (McComb, Ben-Amar & Brown, 1990). Particle shape of amalgam strongly influences microleakage. Mahler and Nelson (1984) found the spherical alloy Tytin to have a greater tendency for anecdotal clinical postoperative sensitivity and in vitro marginal microleakage than the admix alloy Dispersalloy. Other studies have confirmed this tendency for greater microleakage with Tytin alloy (Ben-Amar & others, 1986; Fayyad & Ball, 1984; Saiku, St Germain & Meiers, 1993), and this is most likely due to its setting shrinkage (Brown & Miller, 1993).

A recent study (Saiku & others, 1993) showed Amalgambond/Dispersalloy combinations to have significantly less microleakage in vitro than Amalgambond/Tytin combinations; however, aging for 30 days increased the microleakage. 4-META-lined amalgam restorations demonstrated a sealed internal cavity wall, despite the formation of a gap between the amalgam and resin, which was probably due to SEM vacuum desiccation. Again this shows that the weak link is at the amalgam-resin interface, even with the presence of a resin supposedly capable of additional chemical linkage (4-META). The strongest attachments reported in the literature using amalgam bonding were by Varga, Matsumura, and Masuhara (1986), who obtained an unusually high shear bond strength of 13.4 MPa for a 4-META/MMA-TBB resin on enamel, which increased to

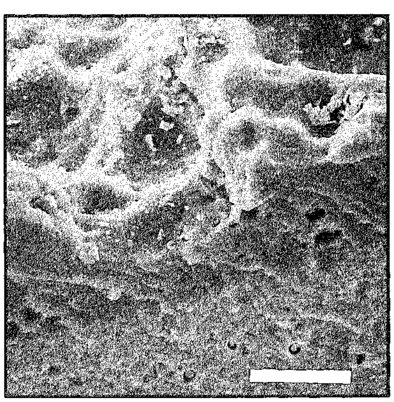

Figure 1. *Sectioned interface after debonding showing residual resin layer securely attached to conditioned and primed dentin. Many spherical amalgam voids are present. (Bar = 10 μm.)*

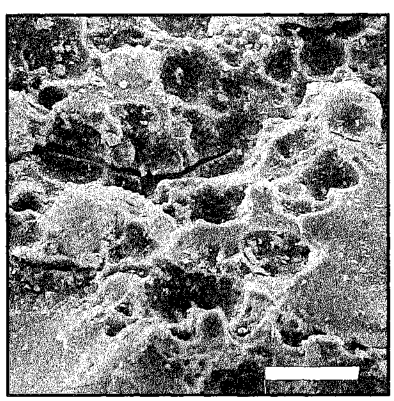

Figure 2. *Tooth surface after debonding with firmly adherent resin layer showing a few retained amalgam spheres (Bar = 20 μm.)*

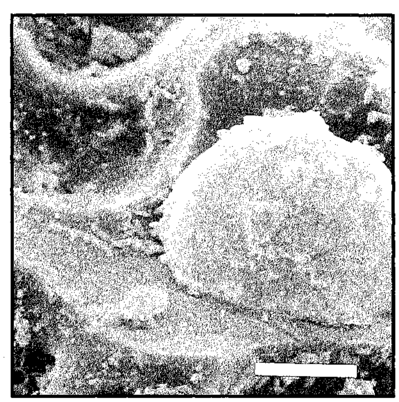

Figure 3. *Higher magnification of debonding tooth surface with detail of mechanically retained amalgam sphere surrounded by similarly shaped voids (Bar = 5 μm.)*

17.7 MPa after 1 month of storage in water. Interestingly, the chemical constituents of the adhesive resin were freshly prepared by the authors, and the results may be reflecting optimal chemical reactivity.

The attachment attained in this study invariably withstood 1000 cycles of impact loading (one debond), but three samples debonded during the 5000 cycles. The resulting shear bond strength after mechanical cycling in each case was markedly reduced. The suggested significance is that the resin-mediated amalgam attachment to tooth will be progressively weakened during function, especially if high occlusal forces are present. Five thousand cycles is a minimal number in terms of masticatory function, and the 700-gram load is at the low end of the physiologic chewing force range. Dental studies examining the effects of occlusal function are few. Thin specimens (1 x 5 x 30 mm) of composite resin were reported to resist between 5000 and 40,000 mechanical cycles, using similar low load values by Drummond (1989). Higher load values of 6 - 10 Kgm have been used to simulate occlusal function in teeth restored with bonded composite resin (Fissore, Nicholls & Yuodelis, 1991). The results were classic in that the smallest load (6 Kgm) required the greatest number of load cycles (71,000) before loss of adhesion. The largest load required only 2600 cycles. In the resin-bonded amalgam the weakest link is the amalgam/resin interface due to the inherent stiffness of amalgam, and it is unlikely this attachment can resist significant impact forces in the mouth long-term. Gliding contacts may be more easily withstood than impact loading, and the combination of enamel and dentin bonding in vivo may provide an additional effect.

Temple-Smithson, Causton, and Marshall (1992) have demonstrated that the value of this technique lies in the increase in energy required to break bonded samples, implying an advantage in fatigue situations due to yielding of the resin adhesive. They suggested that bonded restorations could be at risk when unexpected hard food was encountered and cautioned against the use of this technique as the sole retention for amalgam cores.

The true significance of the amalgam bonding technique may be in its superior sealing efficacy, particularly when spherical alloys are utilized. Increased caries resistance around amalgam bonded restorations has even been suggested (Torii & others, 1988). The results of this study suggest, however, that the reinforcement of tooth structure gained by the resin-mediated amalgam technique may be progressively reduced during occlusal function.

CONCLUSIONS

1. A resin-mediated attachment of 7.11 (± 1.93) MPa was found for Tytin spherical amalgam bonded to dentin utilizing All-Bond 2 resin at 24 hours before cyclic loading.
2. Attachment failure occurred at the interface between resin and amalgam.
3. The attachment mechanism invariably survived minimal mechanical cyclic impact loading (1.5 lb force at one strike/second for 1000 or 5000 cycles), but the resulting shear bond strength was progressively and markedly reduced.
4. The reinforcement of remaining tooth structure gained by the resin-mediated amalgam attachment may be significantly reduced during occlusal function.

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Mechanical Properties and Clinical Performance of a Gallium Restorative Material

J W OSBORNE • J B SUMMITT

Clinical Relevance
At 1 year, the clinical restorations indicate that no teeth or restorations were fractured, and restorations should be polished because of a rough and tarnished surface.

SUMMARY

In a combination clinical/laboratory evaluation, a gallium restorative alloy (Galloy) was assessed for six mechanical properties: compressive strength, diametral tensile strength, creep, hardness, wear, and dimensional change. Laboratory tests indicated that the gallium alloy was similar to either Tytin or Dispersalloy in most respects, with the exception of lower wear and higher 7-day diametral tensile strength. In the clinical trial, all Galloy restorations were lined with a resin to prevent moisture contacting the material during the first hours after placement. All gallium restorations—class 1's only—were intact, and no teeth were fractured at the end of 1 year. There was little difference found at the 1-year evaluation compared to the 6-month results. The surface of the gallium alloy was generally rough, and many restorations exhibited some tarnish on the surface. It should be pointed out that this product has not been FDA approved at the present time and is not on the market.

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INTRODUCTION

Dental amalgam remains the most widely used restorative material. Its durability, ease of manipulation, and cost-effectiveness are the main reasons for its success. Recently, however, the mercury toxicity issue has gained attention, and many papers have been published on the release of mercury from amalgam. Although this amount is low (< 2 μg/12 amalgam restorations/day) (Bergland, 1990; Olsson & Bergman, 1992; Mackert, 1987) and constitutes less than 10% of the patients' intake of mercury from food, water, air, and other sources (Rao & Hefferen, 1981; Vostal, 1972), substitutes for amalgam have been sought.

In the late 1920s gallium was one of the substitutes suggested for mercury (Puttkammer, 1928), and early in the 1950s work by Smith and associates (Smith & Caul, 1956; Smith, Caul & Sweeney, 1956) showed the potential for using a gallium system. These publications lay dormant until recently when the mercury toxicity issue renewed the interest in nonmercury alloys. Two gallium restorative materials have been commercially developed: Galloy (Southern Dental Industries, Bayswater, Victoria, Australia) and Gallium GF (Tokurike Honten, Tokyo, Japan). Studies have been initiated on the mechanical properties (Horibe & others, 1991; Miller & others, 1994), toxicity (Psarras, Wennberg & Dérand, 1992), handling characteristics (Mash & others, 1993), microstructure and anodic polarization behavior (Oshida & Moore, 1993), and clinical efficacy (Yamashita, Itoh & Wakumoto, 1989; Navarro & others, 1993). The purpose of this evaluation was to examine the gallium alloy, Galloy, for certain mechanical properties and to evaluate the clinical performance of the placed restorations at 6 months and 1 year.

METHODS AND MATERIALS

Laboratory Evaluation

The laboratory assessment was conducted to compare the gallium alloy to two high-copper alloys, Dispersalloy (L D Caulk, Milford, DE 19963) and Tytin (Kerr Mfg Co, Glendora, CA 91740). The laboratory tests were: 1) compressive strength at 15 minutes, 1 hour, 24 hours, and 7 days; 2) diametral tensile strength at 15 minutes, 1 hour, 24 hours, and 7 days; 3) creep; 4) hardness; 5) dimensional change at 24, 48, and 72 hours; and 6) wear. All samples of the three alloys were triturated according to their manufacturers' recommendations and were prepared by the ADA specification method (American Dental Association, 1974).

Compressive strength and diametral tensile tests were assessed on a Universal Testing Machine (Instron Corp, Canton, MA 02021) with a crosshead speed of 0.5 mm/min. Five samples of each test cell were tested at the different times. Creep was determined as described by Mahler and Van Eysden (1969). Five samples of each alloy were tested. Knoop hardness was assessed on a Tukon Tester (Wilson Instruments, Inc, Binghamton, NY 13905). Three samples of each alloy were measured in 10 different areas of the alloy specimen. Dimensional change was measured on a microkator (CE Johansson, Eskilstuna, Sweden) for 5 minutes-24 hours, 5 minutes-48 hours, and 5 minutes-72 hours. Five samples of each alloy were measured. Wear was assessed by a three-body wear test (Leinfelder, Beaudreau & Mazer, 1989). Generalized wear for each alloy was tested through 400,000 cycles, and four samples of each alloy were measured for loss of material in eight places by a profilometer (Surfacanalyzer EAS-4100, Federal Products Corp, Providence, RI 02905).

A Student's *t*-test was used to determine statistical difference among the alloys. The level of significance was set at $P < 0.05$.

Clinical Evaluation

Patients were selected who needed two to four class 1 restorations. These could be either new carious lesions or older restorations that required replacement. All patients were in good health and signed the consent form approved by the Institutional Review Board at the University of Texas Health Sciences Center at San Antonio. Nine patients were selected and 30 class 1 gallium restorations were placed by one operator at the clinical research facility in the School of Dentistry at San Antonio.

A rubber dam was utilized throughout the restorative procedure and all cavity preparations were as conservative as possible (Summitt & Osborne, 1992). Deep portions of the preparations received a resin-modifed glass ionomer (Vitrebond, 3M Dental Products, St Paul, MN 55144). After cavity preparations, cavosurface margins and enamel walls were etched for 30 seconds, rinsed with water for 15 seconds, and dried.

Half of the restorations received SDI (Southern Dental Industries) resin material, a BIS-GMA low-viscosity material, as a lining agent. SDI etching gel (37% phosphoric acid) was used to etch the enamel. A thin coat of resin was then applied to all cavity walls and cured with an Optilux 400 (Demetron Research Corp, Danbury, CT 06810) for 20 seconds. The gallium restorative was placed, condensed, and carved. After final carving, the SDI resin was applied to the surface of the restoration and cured (Figure 1).

In the other half of the restorations, Amalgambond (Parkell, Farmingdale, NY 11735) was the resin lining system. Again the enamel cavity walls were etched, rinsed and dried, resin applied to all cavity walls, and in the time frame recomended by Parkell, the Galloy placed, condensed, and carved. As with the other restorations, the surface of the gallium alloy was covered with a thin film of SDI resin and cured. Patients' occlusion was checked and when it was found to be high, a #2 round bur was used to reduce the restoration and the resin reapplied to the alloy surface. None of the restorations was polished postoperatively.

Color and black-and-white photographs were taken with a 200 mm f4.5 Medical Nikon (Tokyo, Japan) lens at X1.5 at baseline, 3 months, 6 months, and 1 year of all the restorations. These photographs were then assessed for tarnish and fracture at the margins. The fracture at the margins was assessed by ridit (Mahler & others, 1970) and tarnish was assessed by placing the photograph of the restoration into two groups: no tarnish or tarnished.

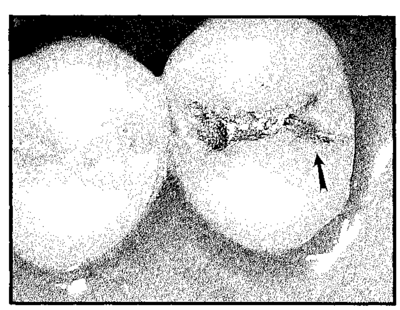

Figure 1. *Gallium restoration at baseline with resin on the surface. Gallium alloy is retained in unprepared fissure (arrow).*

Laboratory Data: Means and (SD)

Compressive Strength—MPa	Galloy	Dispersalloy	Tytin
15 minutes	38.6 (4.6)	42.8 (4.3)	70.4 (3.5)
1 hour	141.9 (18.1)	154.6 (15.1)	281.5 (15.2)
24 hours	421.1 (38.1)	414.0 (27.5)	546.8 (24.9)
7 days	471.3 (28.2)	459.9 (22.3)	551.1 (21.0)
Diametral Tensile Strength—MPa			
15 minutes	4.0 (0.9)	4.0 (0.7)	6.8 (0.7)
1 hour	15.6 (2.1)	13.4 (1.1)	26.6 (2.0)
24 hours	61.9 (7.2)	48.3 (7.6)	61.1 (5.9)
7 days	74.5 (7.6)	50.4 (7.8)	60.5 (6.1)
Creep %	0.09 (0.05)	0.22 (0.09)	0.09 (0.03)
Hardness—KHN	128.0 (19.8)	120.1 (9.4)	124.6 (11.3)
Wear—µm	0.28 (0.5)	3.0 (1.1)	3.0 (1.3)
Dimensional Change—µm/cm			
24 hours	-3.1 (3.1)	-4.9 (3.1)	-6.1 (4.9)
48 hours	-3.0 (2.2)	-4.8 (3.8)	-6.1 (2.1)
72 hours	-3.0 (1.8)	-4.7 (3.9)	-6.2 (3.6)

RESULTS

Laboratory Evaluation

The laboratory data are summarized in the table. Compressive strength for the gallium alloy at all times was equivalent to the amalgam Dispersalloy. Diametral tensile strength was equal to the amalgams up to 24 hours but by 7 days had reached a strength that was 23-48% greater than the high-copper amalgams. Creep values of Galloy were equivalent to Tytin. Knoop hardness for the gallium alloy, although higher than the amalgams, was not significantly higher. Wear of the gallium alloy, interestingly, was significantly less than the high-copper amalgams. The wear of high-copper amalgams was very small: about 3 µm loss during the three-body wear tests. But for the gallium alloy, it was only one-tenth that amount. Dimensional change indicated the gallium alloy had little expansion during the first 72 hours in a dry field, and was the same statistically as for Dispersalloy.

Clinical Assessment

All patients were recalled and the 30 restorations evaluated at all time periods. The 6-month clinical observations are summarized as follows: no resin was found on the gallium alloy at 3 months, no difference was observed between resin-lined and Amalgambond restorations, little or no margin fracture was observed, all restorations were intact (Figure 2), Galloy was still present in the unprepared fissures of some teeth (Figure 3), the gallium alloy did not show a high luster surface and was generally rough, no teeth were fractured, 50% of the restorations exhibited a tarnished surface (Figure 4), and no allergic reactions or medical problems were reported.

The results of the clinical evaluation at 1 year found little difference compared to that found at 6 months (Figure 5). Little or no fracture at the margins was noted. There was no clinical or statistical difference between the resin-lined and Amalgambond restorations with regard to fracture at the margins. All restorations were intact, and none had fractured through the body of the restorations, but the surface lacked a high luster and was generally rough. The Galloy was still present in unprepared fissures (Figure 3), and 57% of the restorations exhibited a tarnished surface (Figure 7). This was an increase over the 6-month clinical data but was not found to be statistically significant (P = NS). No teeth were fractured, and no allergic reaction or

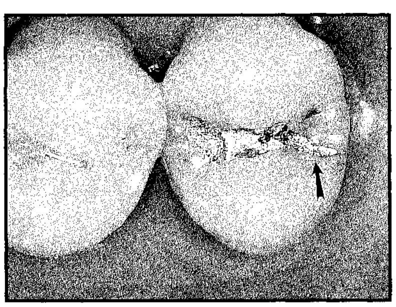

Figure 2. *Same restoration as in Figure 1 at 6 months. Gallium alloy is retained in unprepared fissure (arrow).*

Figure 3. *Restoration at 1 year with a portion of the alloy fractured away in that unprepared fissure (arrow)*

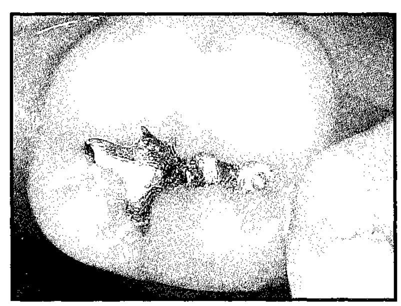

Figure 4. *Galloy restoration at 1 year with a relatively smooth surface*

Figure 5. *Typical 1-year gallium restorations with little tarnish*

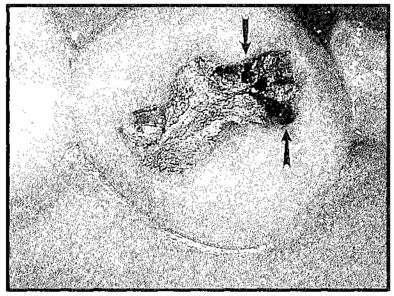

Figure 6. *1-year restoration exhibiting tarnish (arrows)*

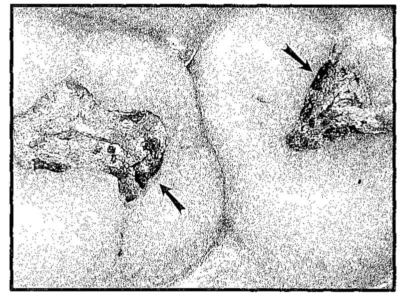

Figure 7. *Gallium restorations with rough surface and tarnish (arrows) seen at 1 year*

medical problems were reported by the patients at the 1-year recall.

DISCUSSION

Laboratory Evaluation

The gallium restorative alloy had many properties that were equivalent to or better than the high-copper amalgams, notably the 7-day diametral tensile strength (23-48% greater) and the extremely low loss of material in the wear test (10 times less). Compressive strength, creep, hardness, and dimensional change all indicate that this gallium alloy may serve as a good restorative and would pass the ADA Specification test.

Clinical Assessment

This study on Galloy was specifically designed as a small pilot program because a clinical study (Navarro & others, 1993) on another gallium product was discontinued due to extremely poor results. The manufacturer of Galloy modified the restorative procedure with the idea that both their gallium alloy and its specific placement procedure would result in improving the clinical performance. The manufacturer, SDI, had data indicating excessive expansion of the restorative material if moisture came in contact with the gallium alloy during the first 8 hours, hence the use of a resin lining agent. Whatever the reason, the 6-month and 1-year clinical data would suggest no major problems with this restorative system under the conditions outlined during the short time it was evaluated.

There was no resin found on the surface of the gallium alloy at 3 months, indicating it had worn off. But the surface was rough and showed no signs of self-polishing. This may be explained by the laboratory wear results. Galloy showed little sign of wearing in the laboratory test, and this resistance to wear may clinically show up as a lack of surface luster. On the other hand, many restorations of Dispersalloy and Tytin show a luster by 6 months, but they also demonstrate a small amount of wear. Because of the surface roughness and increased tarnish, the gallium alloy should be polished at a subsequent appointment after placement. It is the authors' experience that polishing is relatively simple, not time-consuming, completed with standard polishing procedures, and long-lasting.

Although the anodic polarization data on this particular alloy (DeSchepper & others, 1995) indicate that it has a high corrosion potential, this was not noted on the surface of the restorations. If any of these restorations need to be removed for any reason, retrieved material will be analyzed for corrosion.

Some Galloy restorations also had alloy material in the adjacent unprepared fissures at 6 months and 1 year due to its great wetting/adhesive properties (Figures 2 and 3). The tensile properties for Galloy are higher, and therefore it may not break in small areas like fissures as an amalgam does.

One report (Mash & others, 1993) showed that the handling characteristics of the gallium alloy are inferior to high-copper amalgams. The handling of this material was difficult because of the wetting/adhesive properties. This characteristic made the alloy stick to all the condensing instruments and some carving instruments, but it was easily cleaned off. The fresh mix of gallium alloy was initially very plastic but quickly turned noncohesion-like, making it somewhat difficult to handle. But it was found that repeated placement of the gallium restorative in preparations in a typodont prior to the clinical study reduced the perception of poor handling characteristics. Therefore, the difference in handling this alloy was not a distraction in the clinical study. The gallium alloy also left a dark residue on gloves when handled.

There are patients who have an intense desire to avoid having amalgams placed, but they need a metallic restoration. They may warrant a gallium restorative material. Galloy suffers the same esthetic problem as amalgam, but the psychology of a mercury-free metallic restoration may be a benefit to using a gallium substitute.

Reports on subsequent clinical results of this project will be submitted in a timely fashion, and clinical trials are planned that will expand the basic understanding of this product.

Presently the gallium alloys are not approved by the FDA. If and when they are approved, caution should be used until more extensive clinical data are obtained on these restorative materials. Long-term results and studies on class 2 and extensive restorations should be conducted and reviewed by the practitioner. An in-depth review of potential problems associated with these products is also necessary.

CONCLUSION

The 6-month and 1-year results of this clinical trial showed no extensive problems for Galloy. This clinical trial used a resin liner both internally and externally to exclude moisture from the restoration during the first hours after placement. All restorations were intact and no teeth were fractured.

When it becomes approved, the gallium alloy, Galloy, may be an acceptable alternative to amalgam in certain patients who have a strong aversion to dental amalgam.

Acknowledgment

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Evaluation of Factors Affecting the Accuracy of Impressions Using Quantitative Surface Analysis

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Clinical Relevance
Minor movement during the setting of the impression materials will not cause distortion.

SUMMARY

Impression material goes from a plastic to an elastic state during setting. Movement of the impression and excessive seating pressure during this transition can cause distortion in the impressions. The purpose of this study is to determine if the impression distortion is related to movement during setting or to distortion of the putty phase in the two-step impressioning technique. A master model of a maxillary quadrant of teeth was impressed using four different procedures: 1) one-step technique without movement (1S-NM); 2) one-step technique with movement (1S-M); 3) two-step technique without movement (2S-NM); and 4) two-step technique with movement (2S-M). An artificial oral environment and surface analysis technique of the Minnesota Dental Research Center for Biomaterials and Biomechanics were used to produce the impressions and measure their accuracy. A digitized image of the first premolar of the master model was aligned with a digitized image of the first premolar of each epoxy model using AnSur. The root mean squared difference (RMS) between the aligned images is a measure of the distortion.

The corresponding RMS values for the different methods were: 1S-NM = 23.7 ± 9.21; 1S-M = 20.4 ± 3.9; 2S-NM = 20.5 ± 7.7; 2S-M = 21.3 ± 4.4. Statistical analysis using a two-way analysis of variance showed no difference at the 0.05 level of significance. Pairwise comparison using the Tukey method showed that neither technique (one-step vs two-step) nor movement is a significant factor. These results showed that low seating pressure will not cause any greater distortions in the two-step impression technique than in the one-step technique, and minor movement during the setting of the impression material will not cause distortion.

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INTRODUCTION

Indirect restorative procedures in dentistry depend on accurate impressions of restorative preparations. Laboratory studies have shown that the impression materials are very accurate in reproducing details such as the distance between two inscribed lines on a master die (Council on Dental Materials and

Devices, 1977) or a series of lines with varying distances and depths (Ciesco & others, 1981; Johnson & Craig, 1985). However, these tests are not representative of typical clinical situations where the teeth have dramatic three-dimensional shapes and embrasures into which the material may flow and lock itself in place, thereby requiring the material to be torn in order to remove the impression.

The use of the addition-type silicone impression material has been widely accepted by the dental profession because of its elasticity, excellent setting properties (including delay and multiple pouring capabilities), and dimensional stability (Johnson & Craig, 1985; Yeh, Powers & Craig, 1980; Williams, Jackson & Bergman, 1984). Two impressioning techniques are used with the addition-type silicone putty/wash impression system: the one-step and the two-step methods. The one-step technique has the advantage of less chair time, while the two-step technique has the advantage of capturing surface detail with the wash material only. Aside from the inherent accuracy of the material, there are other factors that may affect the accuracy of the impression such as: 1) movement of the tray while the material sets and 2) removal of the tray before the material sets. In the case of the two-step technique, there is the additional factor of seating pressure. Seating pressure applied to the tray while the light body cures may distort the set putty material if the pressure applied is excessive. The one-step technique should be insensitive to this pressure because the wash and the putty materials cure at the same time. If the tray moves while the impression material is changing from a plastic phase to an elastic phase, the movement would be "locked" into the impression, causing the replica to appear distorted. Removal of the tray before the impression material completely sets is an extreme case of movement that obviously results in a distorted replica.

Quantitative techniques exist today that can measure changes in tipsier surfaces very accurately. In clinical studies, these techniques rely on accurate replications of the surfaces. One such technique was developed at the University of Minnesota School of Dentistry (DeLong, Pintado & Douglas, 1985). This profiling system can measure surface changes with an accuracy of better than 7 microns for surface angles less than 60 degrees (Anderson & others, 1993). Accurate replicas of the surface are made using addition silicone impression materials to form a negative image of the surface, and Epoxy-Die (Ivoclar, Schaan, Leichtenstein) to make positive replicas. Digital images of the epoxy replicas are made by profiling

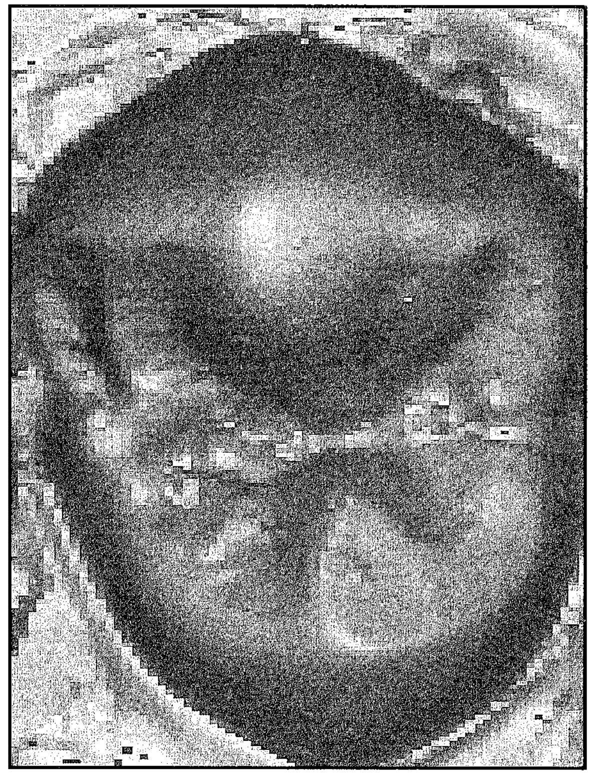

Figure 1. *Quantigraph of the first premolar of the master model. The quantigraph is a shaded gray scale mathematical image constructed from the (x,y,z) point measured by the profiler. The quantigraph shows the quality of the profiler data.*

the replicas' surfaces (Figure 1). Surface changes are identified and measured by comparing "before" and "after" images using the computer software program AnSur (copyright, Regents of the University of Minnesota). The software finds the best alignment of two digital images by minimizing the root mean squared difference between corresponding points of

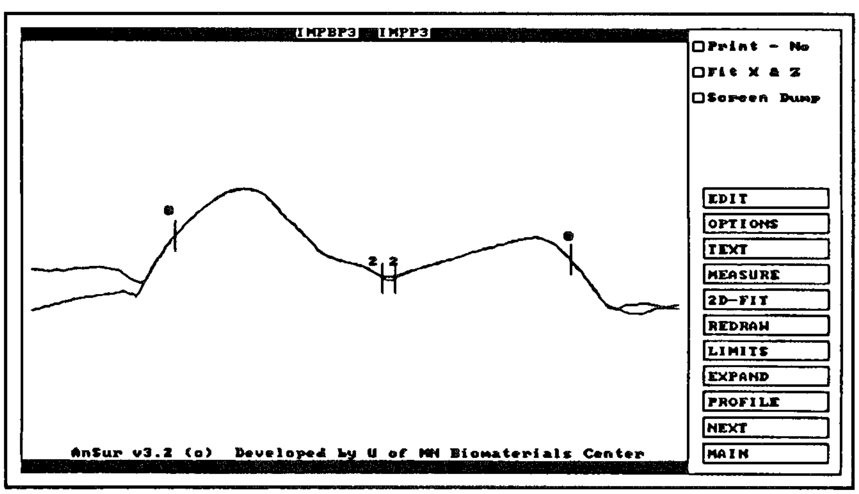

Figure 2. *Superimposed profiles of a "before" and an "after" digitized image using the software AnSur*

the two images. When the best fit is achieved, the profiles can be visually inspected on the computer screen to identify areas of change in contour (Figure 2). These areas can be limited by the screen cursors, and calculations of the mean depth and maximum depth of change of contour can be carried out.

When this quantitative technique is used to evaluate surface changes in clinical trials, a strict protocol is used to impression the surface. On occasion, obvious distortions have occurred during the comparison of "before" and "after" replicas. These distortions do not represent true surface changes; they are distortions in the impression. If the distortion is in the "before" or baseline impression, then data from the patient are lost, because new baseline impressions cannot be taken. To avoid this problem, two baseline impressions are normally made. This requires additional time and expense in the clinical trial.

The purpose of this study is to determine if the impression distortion is related to movement of the patient during setting or to distortion of the putty phase in the two-step impressioning technique. The artificial oral environment and the surface analysis technique of the Minnesota Dental Research Center for Biomaterials and Biomechanics were used to produce the impressions and measure the accuracy of the impressions.

METHODS AND MATERIALS

An epoxy model of a maxillary quadrant of teeth served as the master model for this study. The master model was impressioned using four different procedures: 1) one-step technique without movement (1S-NM); 2) one-step technique with movement (1S-M); 3) two-step technique without movement (2S-NM); and 4) two-step technique with movement (2S-M). Impressions were made according to the following sequence: 1S-NM, 2S-NM, 1S-M, 2S-M. Ten separate impressions were made for each of the four techniques by repeating the sequence 10 times. All impression procedures were performed using the artificial oral environment of the Minnesota Dental Research Center. All impressions set for 24 hours before the replica was made using Epoxy-Die die acrylic. The replicas were mounted on nylon mounting rings using Die-Keen stone (Miles Inc, South Bend, IN 46614). The replicas were profiled using the DC servomotor contact stylus profiler of the Minnesota Dental Research Center. The master model was profiled prior to profiling each of the experimental replicas, thus there were 40 digital images of the master model.

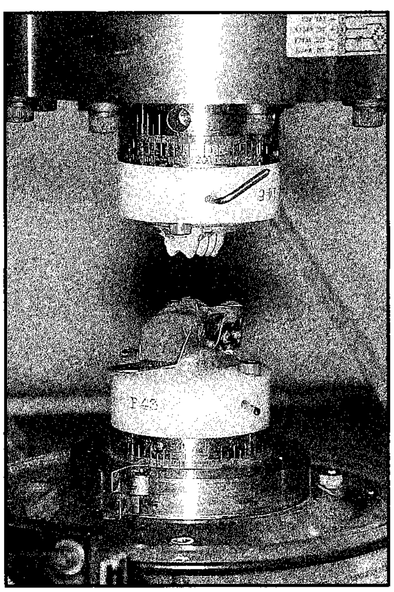

Figure 3. *The master model was mounted on the upper crossmember of the artificial oral environment of the Minnesota Dental Research Center for Biomaterials and Biomechanics. The impression tray was mounted on the lower platen.*

Impression Procedure

The master model was mounted in a nylon mounting ring with Die-Keen stone. The mounted master model was placed on the upper cross-member of artificial oral environment (Figure 3). A jig to hold the impression trays was made on a second nylon mounting ring using self-cured acrylic (Figure 4). The jig allowed the trays to be placed on the machine in a reproducible position. Permabond 910 adhesive (Permabond International, Englewood, NJ 07631) was used to secure the tray onto the mounting ring. The mounted tray was placed on the lower platen of the artifical oral environment. Impression material was loaded into the tray and the lower platen was raised to seat the impression material on the master model (Figure 5). The impression was allowed to set undisturbed for 5 minutes.

In experiments involving movement, the lower platen was moved up and down with a sinusoidal

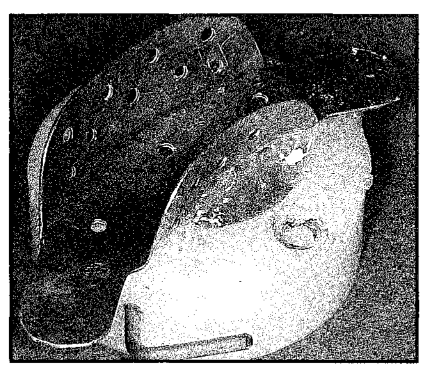

Figure 4. *The impression tray was mounted on a nylon mounting ring using a self-cured acrylic jig.*

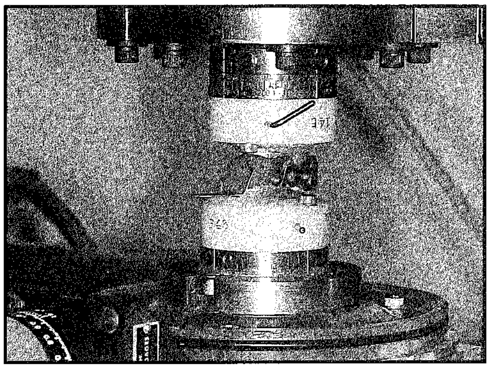

Figure 5. *The impression materials were loaded onto the tray and the lower platen of the artificial oral environment was raised to seat the impression on the master model.*

motion during the setting of the impression material. The cycling rate was 1 Hz with a maximum displacement of ± 250 μ. This movement limit was arbitrarily chosen to simulate minor movement of the impression tray while the impression is setting.

One-step technique: Express putty vinyl polysiloxane impression material (No 7312, 3M Dental Products, St Paul, MN 55144) was hand mixed and placed in the mounted impression tray. Express light body vinyl polysiloxane impression material (Regular set, No 7302H, 3M) was mixed using the automix system. The light body material was placed on the master model and on top of the putty material using the mixing tip. The tray was seated on to the master model and allowed to set for 5 minutes. Twenty one-step impressions were made: 10 without movement and 10 with movement.

Table 1. Comparisons of Master Model Profiled Images

MM 60	RMS/pt (microns)	MM1	RMS/pt (microns)
Image 1 vs 61	4.55	Image 1 vs 3	4.95
Image 3 vs 63	3.70	Image 9 vs 11	3.26
Image 5 vs 65	4.40	Image 17 vs 19	2.89
Image 7 vs 67	11.08	Image 25 vs 27	3.35
Image 9 vs 69	3.91	Image 33 vs 35	3.48
Image 11 vs 71	4.30	Image 41 vs 43	3.37
Image 13 vs 73	4.29	Image 49 vs 51	3.63
Image 15 vs 75	4.08	Image 57 vs 59	3.39
Image 17 vs 77	4.05	Image 69 vs 71	3.27
Image 19 vs 79	4.23	Image 73 vs 75	3.17
Average (± sd)	4.86 (± 2.20)	Average (± sd)	3.58 (± 0.53)

MM60 = comparison of master model images separated by 60 profiled replicas.
MM1 = comparison of master model images separated by one profiled replica.
RMS/pt = root mean squared difference per point.
sd = standard deviation.

Two-step technique: One thickness of baseplate wax was adapted over the master model. Express vinyl polysiloxane putty impression material was hand mixed and placed in the tray. The tray was immediately seated over the master model with the wax spacer in place. After the impression material had set, the impression was separated from the master model and the wax spacer removed. In the second step of the technique, the Express light body material was automixed, then placed on the master model and into the space in the putty provided by the wax spacer. The tray was immediately seated over the master model and allowed to set. Twenty two-step impressions were made: 10 without movement and 10 with movement.

Model Comparisons Using Digitized Images

The maxillary first premolar of each model was digitized by collecting 75 profiles 100 μ apart. Each profile contained 200 points 50 μ apart, for a total of 15,000 points per image. In all cases the master model was profiled prior to the test replica. This formed a "before" (premolar of the master model) and "after" (premolar of the replica) couple. The digitized image of the replica model was aligned to and compared with the digitized image of the master model (Figure 2) using the surface alignment program AnSur. An identical portion on the occlusal surface of the premolar was chosen to be compared for all samples. Obvious defects, such as surface bubbles that occurred on the replicas, were excluded from the alignment region. The root mean squared difference per point (RMS/pt) of the aligned images, calculated for the alignment region, was used to evaluate the different methods. The smaller the RMS/pt, the better the agreement between the master model and the replica.

Statistical analysis was done using two-way analysis of variance. Pairwise comparisons were done using the Tukey method. Statistical significance was set at $P < 0.05$.

RESULTS

The master model was profiled 40 times, once before each of the replica models. The master model digitized images separated by 60 profiled images were aligned and compared using AnSur. The resulting RMS/pt values are shown in column MM60 of Table 1. Similarly, the master model digitized images separated by one profiled image were aligned and compared. The RMS/pt values are shown in column MM1 of Table 1. The mean RMS/pt values are 4.9 ± 2.2 and 3.6 ± 0.5 microns respectively. The means are not significantly different at the 0.05 level of significance.

Table 2. Comparisons of Replica and Master Model Images from Four Impression Methods

IMPRESSION METHODS	1S-M (micron)	2S-M (micron)	1S-NM (micron)	2S-NM (micron)	One-step (1S-M+1S-NM)	Two-step (2S-M+2S-NM)	Movement (1S-M+2S-M)	No Movement (1S-NM+2S-NM)
	20.73	16.69	19.51	20.31				
	17.49	22.21	25.62	15.11				
	21.34	24.54	19.31	13.35				
	24.64	22.61	18.27	17.34				
	18.31	17.99	23.64	16.56				
	15.97	17.40	14.36	13.84				
	15.58	19.17	47.43	20.70				
	18.01	20.98	24.46	19.24				
	24.55	31.55	18.55	36.42				
	26.94	20.50	26.50	31.78				
Average	20.40	21.30	23.70	20.50	22.1	20.9	20.9	22.1
SD	3.90	4.40	9.20	7.70	7.1	6.1	4.1	8.4

1S-M = one-step technique with movement; 2S-M = two-step technique with movement; 1S-NM = one-step technique without movement; 2S-NM = two-step technique without movement; SD = standard deviation; RMS/pt = root mean squared difference per point.

The digitized image of each replica model was aligned and compared with the master model image profiled immediately before the replica. The RMS/pt value measures the quantitative difference between the replica model and the master model. The mean RMS/pt values for the four impression methods are presented in Table 2. The mean RMS/pt values are: 1S-M = 20.4 ± 3.9; 2S-M = 21.3 ± 4.4; 1S-NM = 23.8 ± 9.2; and 2S-NM = 20.5 ± 7.7. Statistical analysis using a two-way ANOVA showed no difference ($P > 0.05$). Pairwise comparison using the Tukey method showed that neither technique (one-step versus two-step) nor movement is a significant factor.

DISCUSSION

The precision of the measuring system is affected by errors associated with the contact profiler and the alignment of two digitized images using the software AnSur. It also depends on the surface being measured. The precision of the measuring system for the master model was determined by comparing sequential digital images (Table 1: MM1), the mean RMS/pt is 3.6 ± 0.5 μ. Thus, approximately 4 μ of the difference between two surfaces can be attributed to the measurement system. The RMS/pt for comparisons of master model images that were separated by 60 consecutive profiled images of either the replica or the master model is 4.9 ± 2.2 μ. This difference of 1.3 μ (4.9-3.6) is a measurement of stylus wear and wear of the master model caused by repeated profiling of its surface. This difference is not statistically significant, and therefore can be ignored. Similar efforts to measure the precision of the system for other teeth yielded RMS/pt values of 10 μ and 8.7 μ (Anderson & others, 1993; DeLong, Pintado & Douglas, 1994). The precision of the system, like the accuracy, is inversely proportional to the steepness of the surface. With a precision of less than 10 μ, this system has proven to be a useful tool for measuring changes in dental tissues.

The seating pressure for the impressions was controlled using the artificial oral environment and was the same for all impressions. Using a stiff tray and under normal seating pressure, the one-step technique should be relatively insensitive to the pressure. This is true because both materials, the heavy body and the light body, can flow in response to the seating pressure. The flow will relieve internal stress, reducing the seating pressure to nearly zero. This is true in the artificial oral environment because the distance between the tray and the master model remains fixed during the setting of the material. The same is not true for the two-step technique. In the second step of the two-step technique, the putty material functions as a tray for the wash step (second step). The seating pressure may compress the already set putty material while the light body cures. Upon removal of the impression, the putty will spring back to its relaxed position. This rebounding of the putty will distort the light body material. The question is, Does this result in a significant distortion?

If the rebound of the putty significantly distorts the light body material, this distortion will be reproduced in the replica model. A corresponding distortion would not occur in the models made from the one-step impressioning technique. Thus, comparing the digital images of the one-step and two-step models with the master model would result in larger RMS/pt values for the two-steps. Results from this study did not show any difference between the one-step replicas (22.1 ± 7.1 μ) and the two-step (20.9 ± 6.1 μ) replicas ($P = 0.59$). In this study, the impression was seated passively onto the master model. The seating pressure would be equal to the pressure required to seat the low-viscosity light body material. In fact, the seating pressure used in this study is similar to the ideal seating pressure used in a clinical setting. The lack of difference between the two techniques indicates that the seating pressure is insufficient to cause significant distortion on the putty material.

Results from this study should not be interpreted as implying that the one- and the two-step techniques are equally effective in a clinical situation. In the second step of the two-step technique, the artificial oral environment machine we used allowed us to seat the putty material to the predetermined and reproducible position. This allowed for an even thickness of wash impression material around the tooth. This is difficult to achieve in a clinical situation. The clinical step in using the two-step technique usually required a "stop" made in the putty step. But even with the help of the stop, sometimes it will be difficult to find the predetermined seating position during the wash step. When the putty is not reseated at the predetermined position during the wash step, there is a potential of distortion of the impression by the seating pressure.

The main effort of the present study was to evaluate whether movement during setting of the impression would cause significant distortion. The concern is that if the impression moves while the material sets, this movement will be captured in the impression, resulting in a distorted impression. To determine if this can cause significant distortions, a 250 μ vertical movement at a rate of 1 Hz was applied during the entire time the impression material set. The statistical analysis found no difference ($P = 0.56$) between the replica models made from the impressions that had no movement (22.1 ± 8.4 μ) and those made from the impressions that had movement (20.9 ± 4.1 μ). The no-movement group's standard deviation (8.4 μ) is two times the standard deviation for the movement group (4.1 μ). The higher standard deviation can be attributed to a few samples with unusually high RMS/pt values (sample 7 of the 1S-NM group and sample 8 of the 2S-NM groups). One possible reason for the high RMS/pt values could be that the impressions were prematurely separated from the master model before the impressions were completely set. The manufacturer's recommendation for intra-oral setting time is 5 minutes. The setting time used in this study was also 5 minutes. Since all the experiments were done at room temperature, it is possible some of these samples were not completely set prior to removal from the master model. Previous pilot work by DeLong and others (1994) showed that replicas made from one-step impressions that set on the bench were slightly more accurate than replicas made from two-step impressions with movement.

These results suggest that minor movement of the patient or the operator while the impression is setting will not significantly affect the accuracy. One possible explanation for this can be attributed to the properties of the addition-type silicone impression materials. Yeh and others (1980) reported that of the elastomer impression materials, addition-type silicone impression materials have the least permanent deformation. The materials have low creep, which suggests an excellent recovery from deformation with almost no viscous flow.

The two-way analysis of variance found no difference between the two impression techniques or significant effects with movement. This is in agreement with a study by Hung and others (1992), who also found that there was no difference between the one-step and the two-step techniques. Because there is no significant difference between the different techniques, the data can be combined. The mean RMS/pt for the pooled data is 21.5 ± 6.6 μ. The precision for the measuring system is 3.6 μ. The difference between the two values is an estimate of the impressioning error, thus approximately 18 μ of this distortion comes from impressioning. The mesiodistal width of the maxillary first premolar used in this study is 7.0 mm, thus the 18 μ represents a distortion of 0.26%. This is in good agreement with the 0.36% distortion of Express as reported by Hung and others (1992).

Occasionally during clinical trials replicas of the same tooth will not align. The assumption has been that this was related either to applying too much pressure to the impression tray or movement of the impression while the material set. This report does not support these assumptions. Two other possible explanations for this distortion are that either the impression material or the die material was not completely set. Both of these explanations need further investigation.

CONCLUSIONS

The present study concluded:

1. There were no significant differences in the accuracy of the one-step and two-step impressioning techniques (one-step versus two-step);
2. Low seating pressure will not cause more significant distortions in the two-step impression technique than in the one-step technique; and
3. Minor movement during the setting of the impression material will not cause significant distortion.

(Received 10 October 1994)

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ANNOUNCEMENTS

25th ANNUAL MEETING of the ACADEMY OF OPERATIVE DENTISTRY

22-23 February 1996
WESTIN HOTEL
Chicago, Illinois

The 25th annual meeting of the Academy of Operative Dentistry will focus on a quarter-century of support for Academy members and clinical dentistry. Thursday will feature Dr Harald Heymann ("Conservative, Esthetic Restoration of Anterior Teeth"), Dr David Mahler (Buonocore Lecture), and Dr Gordon Christensen ("25 Years of Operative Dentistry"). Friday's essayists include Dr Harry Rosen ("Solving and Averting Implant Problems"), Dr Ivar Mjör ("The Next 25 Years of Operative Dentistry"), and Dr James Summitt ("Minimally Invasive Dentistry"). Besides these exciting and outstanding speakers, an excellent Table Clinic session will be held on Friday afternoon. In addition, there are always fun spouse events, a wonderful Gala Reception on Thursday evening, and bountiful shopping on the "magnificent mile."

For meeting information please contact Dr Gregory Smith, P O Box 14996, Gainesville, FL 32604-2996; FAX (904) 371-4882.

GOLD FOIL COURSE

There will be a practical Gold Foil course at the University of Washington on 16-20 September 1996. Participation is limited to 12 people. For more information, please contact either:

Dr Warren K Johnson
3107 W McGraw
Seattle, WA 98199
(206) 282-2416

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1306 N 175th Street
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