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SILVER ANNIVERSARY TREATISE

What Are You, Operative Dentistry?

N H F WILSON • I A MJÖR

As the Academy of Operative Dentistry approaches its silver anniversary year, it is considered appropriate to revisit the question posed by Grainger (1972) in the concluding remarks of his keynote address at the organizational meeting of the Academy: "What then are you, Operative Dentistry?" Grainger's answer followed immediately: "You are the multispecialty of the future ... the hub of the wheel ..." Has operative dentistry remained a multispecialty, and is it the hub of the wheel revolving around the Academy?

G V Black (1908), now more the grandfather than the father of modern dentistry, in his seminal work relating the clinical practice of dentistry to a scientific basis, defined operative dentistry as: "Those operations upon the natural teeth and the soft parts connected with them that are usually performed by the dentist for their conservation, or cure of disease." Blackwell (1948) in his introduction to the eighth edition of Black's textbook, considered operative dentistry to comprise: "... all procedures, including preventive measures, by which the teeth may be conserved, and thus maintain the masticatory mechanism in such a state that the general health will not be endangered." A somewhat narrower approach than first envisaged by Black (1908), but nevertheless one which still encompassed most of the clinical practice of dentistry. The contents of the eighth edition of Black's text (Blackwell, 1948) confirms this view. In addition to consideration of lesions and the treatment of the hard tissues of the teeth, pulp, and periapical tissues, there are sections, for example, on the gingivae and peridental tissues, saliva, health and nutrition, mouth hygiene, and oral manifestations of both systemic and skin disease.

Gilmore (1967), who defined operative dentistry as: "... the prevention and treatment of defects in the enamel and dentin of individual teeth," stated in the preface to his textbook: "Common agreement is that operative dentistry is concerned with prevention and mechanical treatment of the problems associated with individual teeth." Gilmore and authors of subsequent texts, such as Charbeneau, Cartwright, and Comstock (1975), who considered operative dentistry to be "imbued with four fundamental goals—prevention, interception, preservation and restoration," explained in the preamble to their respective texts that the scope of operative dentistry had been reduced following the development of specialty groups in dentistry. This was an event, largely precipitated by the growth of new knowledge in relation to dental diseases and oral health care, that, according to Grainger (1972), caused operative dentistry to "... burst its seams from internal, intellectual pressures." Creative people were lost, taking with them the excitement and commitment to

University of Florida, College of Dentistry, Department of Operative Dentistry, Health Science Center, P O Box 100415, Gainesville, FL 32610-0415

Nairn H F Wilson, PhD, MSc, BDS, FDS DRD RCSEd, FDS RCS Eng, visiting professor

Ivar A Mjör, Dr odont, MSD, BDS, professor and Academy 100 Eminent Scholar

build new organizations and disciplines conceived from seeds nurtured and sown in operative dentistry.

From the above, and related literature, it would appear that the recognition of specialty groups in the United States in 1947 had a profound effect on operative dentistry as it had been taught and practiced subsequent to 1908. During the 1950s operative dentistry went through a difficult period, with some of those who remained within the discipline having at times been considered "... guilty of a failure to see the rapidity with which the world around them was moving" (Grainger, 1972), widening the gap between what was believed and reality.

The definition of operative dentistry included in the third edition of the *Art and Science of Operative Dentistry* (Sturdevant & others, 1995) is ".... the art and science of the diagnosis, treatment, and prognosis of defects of teeth which do not require full coverage restorations for correction; such treatment should result in the restoration of proper tooth form, function, and esthetics while maintaining the physiological integrity of the teeth in harmonious relationship with the adjacent hard and soft tissues; all of which enhance the general health and welfare of the patient." When this definition is considered, it could be argued that specialization, including the recognition of endodontics as a specialty in 1963, has been to the long-term detriment of operative dentistry as it is now taught and practiced in the United States. Alternatively, the definition of operative dentistry adopted by contemporary authors of certain textbooks may have clouded the issue by describing a succinct summary of the contents and thrusts of the texts as a definition. However, these definitions are at least wider than some recent dictionary definitions of operative dentistry, such as the one included in the fourth edition of *Boucher's Clinical Dental Terminology* (Zwemer, 1993): "The branch of dentistry that deals with the esthetic and functional restoration of the hard tissues of individual teeth."

When the definition of operative dentistry included in the *Glossary of Operative Dentistry Terms* produced by the Academy of Operative Dentistry (1983) is taken into account ("... that branch of dentistry which relates to diagnosis, prognosis, or treatment of teeth with vital or nonvital pulps; to the maintenance or restoration of the functional and physiological integrity of the teeth as this applies to the adjacent hard and soft tissue structures of the oral cavity"), a more reassuring perspective emerges. Despite specialty recognition and its many effects, operative dentistry, in the view of many who presently practice, teach, and research it, would appear to continue to cover the prevention, diagnosis, and treatment of all sequelae of dental caries in the widest sense, embracing the full spectrum of techniques and procedures for the replacement of lost and defective dental tissues on individual teeth. In this form operative dentistry, like conservative dentistry in other parts of the world, spans all the biological reactions of the dentin-pulp complex, cariology, wear and trauma of individual teeth, and the failure of existing restorations. It also has implications for the periodontal tissues and for orofacial function. In addition, it embraces the chemical, biological, and clinical properties and performance of restorative materials, together with the instrumentation and techniques for the preparation of teeth to receive restorations. But, as highlighted in a recent editorial (Mjör, 1995), where endodontics has divorced from operative/conservative dentistry, it has taken with it the pulp-dentin complex, its structure, ultrastructure, physiology, pathology, immunology, and reaction patterns.

Without expertise and input into further understanding in the field of pulp-dentin biology, let alone all the other related disciplines, it is considered unlikely that operative dentistry can successfully sustain its role as defined in the Academy's glossary of terms. At one and the same time operative dentistry cannot complete the necessary transition from mechanistic dogma to a biologically oriented approach to the preservation and, where necessary, restoration of teeth. Operative dentistry, which may be viewed as preventive endodontics (Mjör, 1995), and endodontics as it has evolved, are inextricably linked, both together and with related disciplines in dentistry, and should work together to their mutual advantage for the benefit of present and future generations of patients.

The concept of overlapping, interdependent disciplines, rather than clearly defined areas of clinical practice and academic endeavor, may cause substantial discomfort to colleagues and organizations seeking tidy compartmentalized arrangements within dentistry, i e, the extension and expansion of specialty recognition. However, if such ambitions are realized, aspects of dentistry, such as operative dentistry, may be further compromised. Specialization is indicated where unique knowledge and skills beyond those commonly possessed by general practitioners is appropriate, but it must benefit dentistry and oral health.

The time has come when operative dentistry must look again at Grainger's question, which in the present climate, may be usefully shortened to simply: What are you, operative dentistry? Operative dentistry is either a broad-based discipline as was originally conceived by Black (1908) and defined in the *Glossary of Operative Dentistry Terms* produced by the Academy of Operative Dentistry (1983), or a much narrower subject area focused on the defects of vital teeth which do not require full coverage

restorations for correction (Zwemer, 1993; Sturdevant & others, 1995). As stressed by Mjör (1988), it is important to manage the evolution of operative dentistry, mindful that the need for operative treatment will be increasing in some countries and decreasing in others. The aims and objectives for operative dentistry must be global, and as a consequence, broad-based. These aims and objectives will inevitably overlap to a greater or lesser extent with those aims of the interdependent disciplines within the wide subject area of restorative dentistry, and, as originally conceived, should be in the context of the totality of dentistry.

Responsibility for the preservation and further evolution of operative dentistry cannot be considered to be vested in a single organization. The future of the multispecialty, as it should be, whether it continues to be called operative dentistry or some other name, is a responsibility shared by all those with involvement and interests in the discipline, and its fundamental role in dentistry. Operative dentists and colleagues in conservative dentistry, endodontics, cariology, and aesthetic dentistry all have a part to play in the process. The way forward will, for many, involve new working relationships with colleagues in established specialties. Similarly colleagues in established specialties should review their position. Can dentistry as a whole succeed in its mission if there is further distinction among overlapping disciplines, and subjects such as operative dentistry are further compromised? What cost tomorrow for yesterday's shortsighted goals?

In answering the questions revisited in this treatise, those who rise to the challenge should draw inspiration from the following extract from the concluding paragraphs of Grainger's paper (1972): "Operative Dentistry must look at its fundamentals in the light of the future. Operative Dentistry must accept the challenge of a restorative and biologic multispecialty. Cavity preparation and restoration is only a beginning. Expertise must cross over into a deep understanding of the occlusion, the pulp, the periodontium, biomaterials, nutrition, histochemistry, and microbiology so that we can manage this array of scientific information in the clinical practice of operative dentistry. The discipline of Operative Dentistry must shrug off its apathy, recognize its worth and dominate once more the direction that dentistry must take. Let us move Greene Vardiman Black into the next lifetime, give him back his energy in an environment that demands a forward look at this, our world of mouths and teeth and tissues. We are skilled in producing skeptics, but not very good at producing individuals who can create their own framework for values. The first step towards the reconstruction of professional values is the rediscovery of values in one's own tradition (Gardner, 1970). G V Black gave us that tradition one lifetime ago.

"Dentistry, all dentistry, needs a common purpose, a binding principle, some instrumentality for insuring that common goals and excellence are in fact accomplished. What is more logical than Operative Dentistry? ... What then are you, Operative Dentistry? You are the multispecialty of the future ... the hub of the wheel ... "

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ORIGINAL ARTICLES

Tunnel Defects in Dentin Bridges: Their Formation Following Direct Pulp Capping

C F COX • R K SÜBAY • E OSTRO
S SUZUKI • S H SUZUKI

Clinical Relevance
This study reemphasizes the need to employ biologically relevant measures that will provide a long-term clinical seal against microleakage following direct pulp capping with $Ca(OH)_2$ medicaments alone.

SUMMARY

This study was conducted to observe the formation and nature of tunnel defects in dentin bridges, assess the nature of the associated soft tissue elements, and note the relationship of pulp inflammation and necrosis associated with these defects. A total of 235 teeth with class 5 cavity preparation exposures were randomly distributed throughout the dentitions of 14 adult rhesus monkeys. Each pulp was exposed and left open to the oral microflora at one of four time intervals, flushed with saline, debrided, capped with one of two hard-set calcium hydroxide medicaments [$Ca(OH)_2$ (Dycal or Life)] and restored with a dispersed-phase amalgam alloy. Observation times were 14 days, 5 weeks, and 1 and 2 years. A total of 192 dentin bridges formed against the $Ca(OH)_2$ medicaments Life or Dycal in 235 pulp-capped teeth. Considering all four capping periods, 89% of all dentin bridges contained tunnel defects (172 of 192). Forty-one percent (78) of the 192 dentin bridges were associated with recurring pulp inflammation or necrosis and were always associated with the presence of inflammatory cells and stained bacterial profiles. This study demonstrates that a statistically significant number of dentin bridges contain multiple tunnel defects, most of which appear to remain patent. These patent tunnels fail to provide a hermetic seal to the underlying pulp against recurring infection due to microleakage. Most $Ca(OH)_2$ medicaments have been reported to disintegrate and wash out after 6 months, leaving a void underneath the restoration and thereby a pathway for bacterial infection. This study reemphasizes the need to employ biologically relevant measures that will provide a long-term clinical seal against microleakage following direct pulp capping with $Ca(OH)_2$ medicaments alone.

The University of Alabama at Birmingham, School of Dentistry, Departments of Restorative Dentistry and Biomaterials, 1919 Seventh Ave S, UAB - University Station, Birmingham, AL 35294-0007

Charles F Cox, DMD, FADI, professor of dentistry

R Kemal Sübay, DMD, MS, doctor of endodontics, University of Istanbul, Department of Endodontics, Istanbul, Türkiye

Ed Ostro, DDS, MS, associate professor, McGill University, Department of Prosthetic Dentistry, Montreal, Canada

Shiro Suzuki, DDS, PhD, associate professor, Department of Biomaterials

Satoko H Suzuki, DDS, associate research scientist, Department of Biomaterials

INTRODUCTION

A comprehensive review of the pulp-capping literature (Baume & Holz, 1981) reported a 90% incidence of new dentin bridge formation in exposed pulps. Many authors maintain that regeneration of a new dentin bridge is a sign of successful pulp treatment. However, this only appears to be true when a long-term bacterial seal is effected and maintained. Studies (Hess, 1950; Nyborg, 1955, 1958; McWalter, el-Kafrawy & Mitchell, 1976; Ichikawa, 1976; Cvek, 1978; Haskell & others, 1978; Heys & others, 1980, 1981; Cox & others, 1982; Pitt Ford & Roberts, 1991) have reported that pulp healing and new dentin bridges form when exposed dental pulps are direct capped. Others (McWalter, el-Kafrawy & Mitchell, 1973; Watts & Paterson, 1979; Holland & others, 1982) have suggested that a dentin bridge will form against $Ca(OH)_2$ capping when exposed pulps are direct capped. Eda (1961) showed evidence of a bordering zone that developed at some distance from the level of pulp amputation, and Schröder (1972) speculated that $Ca(OH)_2$ provoked coagulation necrosis due to its high alkalinity. Clarke (1970) postulated that a complete ring of reparative dentin encircles the wound in a circumferential manner from the periphery of the exposure site, and that the dentin bridge fills in towards the center of the wound.

However, others have reported that dentin bridges are incomplete in their formation following direct pulp capping and healing. Zander (1939) reported inflammation, and Schröder (1972) reported coagulation necrosis under what appeared to be complete dentin bridge formation. However, neither reported tunnels within the new dentin bridges. Schröder and Granath (1972) reported that the first-formed hard tissue of any dentin bridge is irregular with tubular openings or canalicular lumina, which contain vessels and cells, but will further differentiate to form tubular dentin. Rowe (1967), Watts and Paterson (1979), and Cox and Bergenholtz (1984) reported vessel-filled porosity defects or voids within the substance of new dentin bridges. Langeland and others (1971b) questioned the nature of a complete dentin bridge by showing recurring spaces in serial sections adjacent and throughout the so-called complete dentin bridge. These perforation spaces were often filled with soft tissue inclusions and inflammatory cells. Russo, Holland, and Souza (1982) demonstrated that dentin bridges in human teeth were porous to dyes. Scanning electron microscopic studies by Ulmansky, Sela, and Sela (1972) and Goldberg, Massone, and Spielberg (1984) showed large multiple tunnel defects with cellular elements in dentin bridges of human premolars following pulp capping with $Ca(OH)_2$. A long-term capping study (Cox & others, 1985) showed recurring pulp inflammation and necrosis associated with tunnel defects in dentin bridges. Mjör (1972) cautioned that capping of young healthy pulps may lead to a poor prognosis and that the presence of a dentin bridge itself is not a proper criterion for successful long-term pulpal healing. He also reported that many of the hard tissue bridges contained strings of pulp tissue that traversed the hard tissue (Tronstad & Mjör, 1972). Walton and Langeland (1978) reported that seemingly unbroken dentin bridges often contain multiple perforations and suggested that the use of the term "dentin bridge" is a myth, due to the presence of imperfections in most bridges. The presence of imperfections is demonstrated in the data of Russo and others (1982).

This study of hard-tissue formation was completed to observe and evaluate the incidence of tunnel defects in new dentin bridges after pulp capping with two commercially available hard-set $Ca(OH)_2$ medicaments at various time intervals.

METHODS AND MATERIALS

This study of pulp capping and dentin bridge formation was carried out on 235 noncarious class 5 cavities that were distributed throughout the dentitions of 14 adult rhesus monkeys. Prior to operative procedures, each monkey was sedated with an intramuscular injection of Ketamine hydrochloride (Parke Davis, Rochester, MI 48307) and xylazine (15 mg/kg body weight). Each tooth was mechanically exposed using an ultra-high-speed air turbine (200-300,000 rev/min) with an air-water spray and a new inverted cone carbide bur (ISO size 010) on every fourth tooth. Following exposure to oral microflora for various time periods (Cox & others, 1982, 1985), each preparation was mechanically debrided with a curette, rinsed with sterile saline, and, following hemorrhage control, was capped with one of two hard-setting $Ca(OH)_2$ materials. The remainder of the preparation was sealed to the cavosurface margin with Dispersalloy amalgam. No other intermediate liners or therapeutic treatments were employed. Seven teeth were direct pulp capped and observed at 14 days, 135 teeth were direct pulp capped for 5 weeks, 42 teeth were direct pulp capped for 1 year, and 51 teeth were direct pulp capped for 2 years. Preparatory to sacrifice, each animal was sedated with sodium pentobarbitol (25 mg/cc) and given approximately 1000 units of heparin sodium (Oraganon Inc, West Orange, NJ 07052) to prevent clotting and capillary obstruction during vital vascular flushing. A 10-minute left ventricular flush with 0.9% physiologic saline flush was completed, followed by a 15-minute vascular fixation using a glutaraldehyde phosphate buffered paraformaldehyde GTA-PBF, as per Cox and others (1982). Each tooth was cut from its surrounding alveolus, given a code number, and post-fixed in fresh

GTA-PBF at room temperature. After 24 hours, solutions were changed to 0.5M EDTA (pH 7.2) for demineralization. Following radiographic confirmation of endpoint demineralization, each tooth was rinsed through 20 changes of distilled water. Dehydration was carried out through ascending grades of N-butyl alcohol. Each tooth was embedded in Paraplast Plus (Sherwood Medical, St Louis, MO 63103) and serial sectioned in a sagittal plane at 7μm. Slides were alternately stained with hematoxylin and eosin, Preeces trichrome, and a bacterial stain (McKay, 1970). In order to observe the histological nature of each dentin bridge, complete mesiodistal serial sections were cut, beginning before the exposure and through the entire tissue of the dentin bridge and beyond into the bulk of normal secondary dentin. Histologic evaluation was carried out following previously defined criteria (Cox & others, 1982, 1985; Cox & Bergenholtz, 1986). Each dentin bridge was observed via serial sections for the presence of single or multiple tunnel defects and whether they were present within the center or at the periphery of the dentin bridge interface.

RESULTS

This study histologically evaluated 235 mechanically exposed pulps that had been capped with various hard-set $Ca(OH)_2$ medicaments. A total of 192 new hard-tissue dentin bridges were organized, of which 172 (90%) presented tunnel defects. Generally the healed pulps at 1 and 2 years following direct capping presented with stained dentin bridges. However, the pulp tissues subjacent to these dentin bridges were also associated with recurring pulp inflammation and necrosis as summarized in the table.

14-Day Hard-Tissue Repair

The 14-day exposed and pulp-capped teeth showed six of seven teeth with new hard-tissue dentin bridges adjacent to the medicament interface. All six dentin bridges showed multiple tunnel defects, which were seen as small lakes of pulp tissue, observed directly adjacent to the medicament interface (Figure 1). These tissue lakes were always associated with small blood vessels coursing from the wound site in continuity with the deeper vessels of the reorganizing granulation tissue of the pulp. The dentin bridges all presented normal patterns of tubular dentin, and were seen forming along the entire medicament interface, except at the lakes and at the periphery of the exposure. Normal pulp tissue was present below the dentin bridge, with odontoblastoid cell profiles along the dentin-pulpal interface. No inflammation or stained bacteria were seen in any teeth. No internal resorption was present in any of these pulps.

Number of Direct Capped Pulps with Dentin Bridges and Number of Tunnel Defects per Dentin Bridge per Time Period

	Exposed & Capped Teeth	Dentin Bridges	Tunnel Defects	Inflamed or Necrotic Pulps
14-day capping	7	6	6 (100%)	0
5-week capping	135	103	94 (91%)	43 (46%)
1-year capping	42	34	29 (85%)	17 (59%)
2-year capping	51	49	43 (88%)	18 (42%)
Total teeth	235	192 (82%)	172 (89%)	78 (45%)

5-Week Hard-Tissue Repair

The 135 exposed and pulp-capped teeth observed at 5 weeks showed 103 dentin bridges. Ninety-four (91%) of these dentin bridges presented tunnel defects. Histologic sections through the center of each exposure site showed that each dentin bridge was composed of tubular dentin (Figure 2). However, further mesial or distal histological sections of the same dentin bridges showed several tunnel defects with vessels and cells coursing towards the axial edge of the exposure site (Figure 3). Often these tunnel defects formed a soft tissue lake between the medicament interface and a portion of the original axial floor. Forty-three dentin bridges, each with tunnel defects, showed stained bacterial profiles with both acute and chronic inflammatory cells in the subjacent pulp tissue. No internal resorption was seen in any of the pulps.

1-Year Hard-Tissue Repair

The 42 exposed and pulp-capped teeth at 1 year showed 34 dentin bridges with 29 (85%) multiple tunnel defects. Most dentin bridges were composed of tubular dentin with few cellular inclusions except in the area of the tunnel defect. Most of the dentin bridge defects ran as tunnels from the lake of debris below the medicament, along the axial edge of the exposure site of the dentin bridge to the deeper pulp (Figure 4). Cellular debris, inflammatory cells, and capillaries were present in the pulp tissue below the tunnel orifice at the pulp interface. Adjacent serial sections showed stained bacteria lying in debris below the medicament interface and the defect at the axial wall of the cavity preparation (Figure 5). Seventeen dentin bridges, each with tunnel defects, showed inflammatory cells and stained bacteria. No internal resorption was seen in any of the pulps. Ingested particles of the pulp-capping medicament

were often seen in fibroblast profiles within the subjacent pulp tissue underlying the various tunnels.

2-Year Hard-Tissue Repair

The 51 exposed and pulp-capped teeth at 2 years showed 49 dentin bridges, of which 43 contained multiple tunnel defects. Eighty-eight percent of the dentin-bridged exposures had tunnel defects at the 2-year observation period. Most dentin bridges were composed of tubular dentin except in the areas of the defect. Serial sections indicated that most dentin bridges showed multiple tunnel defects coursing from the medicament interface along the axial edge to the pulp. Each of the tunnels contained both fibroblasts and small capillaries (Figure 6). Eighteen dentin bridges showed inflammatory cells and stained bacteria lying in the lake area directly below the medicament in the tunnel defect. The capillaries and connective tissue below the remaining medicament communicated with the pulp through the tunnel defects and often showed various types of inflammatory cells. Certain of the fibroblasts presented with ingested particles of the pulp-capping medicament. No internal resorption was seen in any pulps.

DISCUSSION

Our data demonstrate that exposed and inflamed primate dental pulps often heal and form new dentin bridges directly adjacent to hard-set $Ca(OH)_2$ medicaments at the same level of success as reported by many other investigators (Zander, 1939; Nyborg, 1955, 1958; Rowe, 1967; Clarke, 1970; Langeland & others, 1971a; Tronstad & Mjör, 1972; Mjör, 1972; Ulmansky & others, 1972; Schröder & Granath, 1972; Walton & Langeland, 1978; McWalter & others, 1973, 1976; Watts & Paterson, 1979; Cvek, 1978; Haskell & others, 1978; Heys & others, 1980, 1981; Baume & Holz, 1981; Cox & others, 1982; Russo & others, 1982; Goldberg & others, 1984; Cox & Bergenholtz, 1984; Cox & others, 1985; Pitt Ford & Roberts, 1991). However, in addition to supporting that data, this study also shows that 89% of all dentin bridges contain multiple tunnel defects. In addition, each tunnel is patent and communicates with the underlying pulp from the medicament interface. However, our data do not agree with the suggestion of Ulmansky and others (1972), who stated that the quality of the bridge improves as the odontoblasts migrate apically with the deposition of dentin. These multiple tunnel defects present a morphological disruption of the dentin bridge barrier in that they not only fail to provide a permanent barrier, but they also fail to provide a long-term biological seal against bacterial infection. Consequently, the tunnels, via recurring microleakage, permit oral contaminants such as bacteria and their toxic factors to eventually gain access to the pulp tissue through the marginal gap. It is the presence of bacterial factors via microleakage that is responsible for pulp inflammation and necrosis and not the medicament per se. We agree with Langeland and others (1971a,b), Tronstad & Mjör (1972), Mjör (1972), and Woehrlen (1977) when they cautioned that histologic demonstration of only one section through a dentin bridge following capping of an exposed pulp is not by itself a proper criterion for maintenance of long-term pulpal healing.

Presence of capping particles in the connective tissue of the pulp at each time interval indicates that the $Ca(OH)_2$ or other filler components of the medicament interface are in a progressive state of disintegration. This softening and disintegration phenomenon of $Ca(OH)_2$ cements has been reported by McComb (1983) and Hwas and Sandrik (1984). Another disadvantageous feature was reported in an in vitro study (Reinhardt & Chalkley, 1983), which reported that $Ca(OH)_2$ bases allow as much or more long-term softening of the adjacent composite resin interface than do other cements such as ZOE, IRM, or Cavitec. And Phillips and others (1984) reported a significant difference in resistance of certain hard-setting $Ca(OH)_2$ materials to attack and eventual dissolution by phosphoric acid-etching solutions. These observations pose an interesting question as to the long-term efficacy of using any commercially available $Ca(OH)_2$ base underneath a clinical composite procedure. Following placement and long-term dissolution of the commercially available Life or Dycal and subsequent migration of capping particles through the tunnels defects, the long-term therapeutic capacity of $Ca(OH)_2$ is now placed in serious doubt! Capping particles are often observed in both macrophages and giant cells of the subjacent pulp below the tunnels. In the deeper pulp tissue, these capping particles appear in long fibroblast-type cells (Figure 7). However, their presence does not seem to provoke a chronic inflammatory response. In addition, the presence of either the $Ca(OH)_2$ and other filler particles does not seem to initiate or to be involved in the internal resorption phenomenon as was reported in primary human molars (Via, 1955). However, it should be noted that Via's study was a radiographic interpretation, as no histological tissues were prepared for evaluation.

This study demonstrates a high rate of recurring infection from the bacterial and oral microcontaminants through dissolution of the $Ca(OH)_2$ at long-term intervals even though dentin bridges are present as indicators of initial healing.

Clinical Considerations

From a clinical standpoint, the ultimate failure of pulp capping is an inability of the medicament to

Figure 1. *Pulp of a Life $Ca(OH)_2$ direct capped exposure after 14 days. Note the dark stained Life $Ca(OH)_2$ on the mid-left of the field (a). Tunnel defects (arrows) are seen across the medicament-pulp interface between the dentin bridge islands. Reorganizing granulation tissue is seen in the upper right of the field with small vessels coursing to the deeper pulp. Normal pulp tissue is seen in the lower left below the dentin bridge, with new odontoblastoid cells along the new dentin-pulpal interface. (Masson trichrome, original magnification X34.5)*

Figure 2. *Pulp of a Life $Ca(OH)_2$ direct capped exposure after 14 days. A new dentin bridge (arrow) is seen along portions of the medicament interface, except at the lower right periphery. Several vessels are present as clear spaces throughout the pulp. New reparative dentin matrix is seen around the periphery of the dentin chips (a) in the pulp and along the original dentin-pulpal wall interface, above and below. All reparative dentin zones show new odontoblastoid cells with red stained nuclei. (Masson trichrome, original magnification X32.5)*

Figure 3. *Pulp of a Life $Ca(OH)_2$ direct capped exposure after 21 days. A new dentin bridge (arrows) is seen along most of the medicament interface, except at the extreme right. The cleared vessels throughout the pulp are a consequence of vascular perfusion. New reparative dentin matrix (a) is seen along the original dentin-pulpal wall interface. Several histiocytes (b) are seen in the mid-central pulp with ingested particles of Life. (Masson trichrome, original magnification X34.5)*

Figure 4. *Pulp of a Dycal $Ca(OH)_2$ direct capped exposure after 13 months. A thick dentin bridge (a) is seen at the left of the exposure site composed of tubular dentin and reparative dentin matrix deposited around the dentin chips pushed into the pulp from the bur exposure. A portion of a tunnel filled with debris (arrow) is seen coursing towards the pulp through the middle portion of the dentin bridge. Several cleared vessels are seen throughout the pulp. (Masson trichrome, original magnification X34.5)*

Figure 5. *Peripheral edge of a dentin bridge of a Life direct capped exposure at 13 months. Note the dark stained Life $Ca(OH)_2$ (a) across the upper field. Yellow stained dentinal tubules (b) are seen on the upper right, with many purple-blue stained bacterial profiles (c) to the left and lower mid-field. (modified McKay bacterial stain, original magnification X162.5)*

Figure 6. *Periphery of a dentin bridge (a) of a Dycal direct capped exposure at 2 years. Dycal is seen on the left with a tunnel coursing from the upper left through the bridge to dental pulp. The tunnel shows red and light pink stained debris (b). Dark staining nuclei of chronic inflammatory cells are seen in the mid-pulp below the tubular dentin of the bridge and peripheral reparative dentin. Several small vessels are present in the connective tissue among the inflammatory cells. Some cells show ingested particles of the Dycal (c). (Masson trichrome, original magnification X41.4)*

Figure 7. *Pulp of a Dycal $Ca(OH)_2$ direct capped exposure after 13 months. Note the dark stained nuclei of the pulp fibroblasts within the connective tissue subjacent to the tunnels. Many of the cells show multiple aggregates of small dark stained $Ca(OH)_2$ capping particles (a) in fibroblasts, macrophages, and histiocytes throughout the field. (Masson trichrome, original magnification X345)*

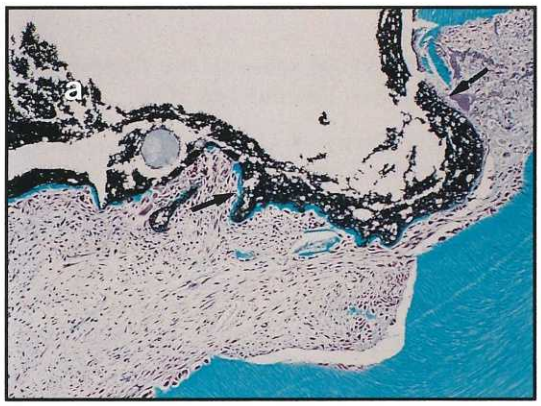
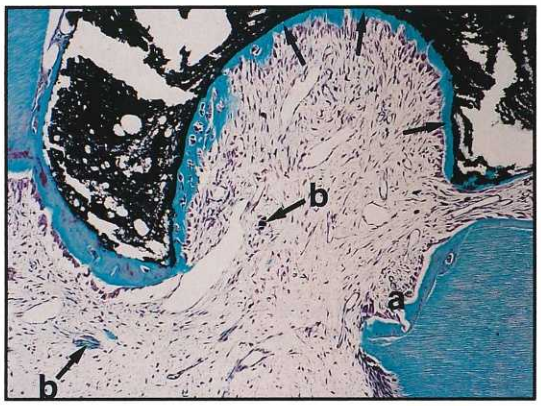


Figure 1.

Figure 2.



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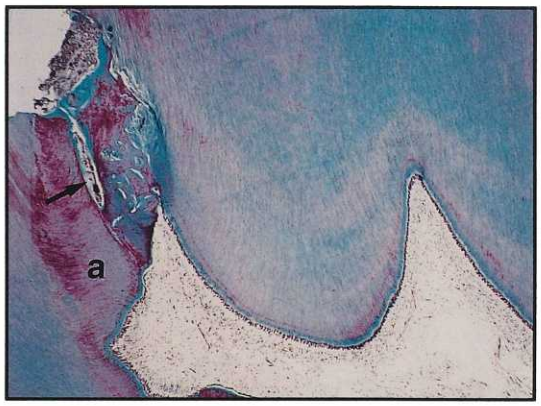

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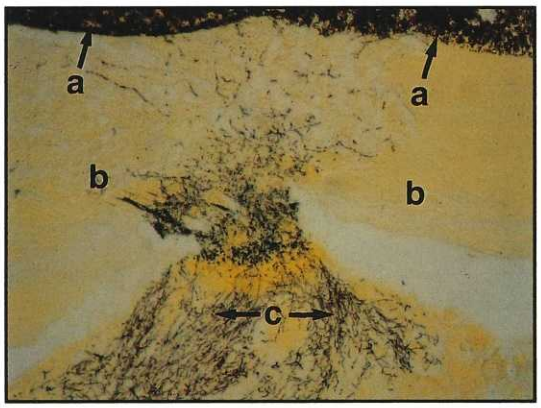

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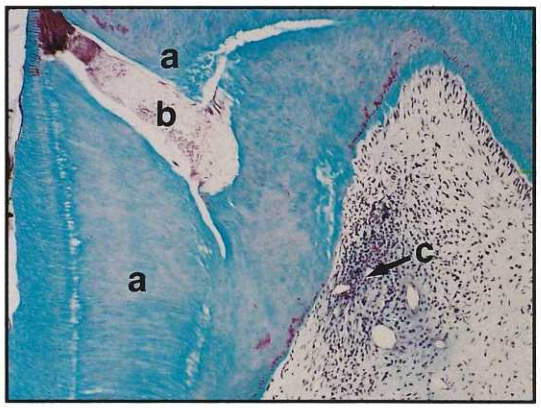

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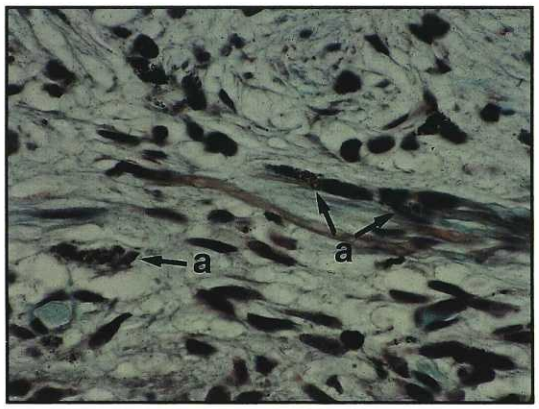

Figure 7.

provide a long-term barrier to microleakage of bacteria and other irritants. At this point, direct pulp capping is considered by many clinicians to be a definitive or permanent procedure. However, it is apparent from this study that the dentin bridges that form under $Ca(OH)_2$ medicaments demonstrate a high rate of multiple tunnel defects (89%) and that the $Ca(OH)_2$ medicaments disintegrate and become lost over a period of time. This observation agrees with the clinical reports of Akester (1979), Barnes and Kidd (1979), and Lewin (1980). Consequently, these hard-set $Ca(OH)_2$ medicaments fail to provide an effective permanent barrier to microleakage of bacterial toxins through the cavosurface margin. This study and other data (Tronstad & Mjör, 1972) indicate that direct pulp capping as currently practiced with $Ca(OH)_2$ is not a permanent definitive procedure and that histological demonstration of only one section of a dentin bridge is no criterion of successful pulp healing. As discussed by others, only histological slides made in complete serial series should be considered to provide definitive information regarding the success of complete dentin bridge formation. Cvek (1978) suggested removal of the temporary restoration and capping material after 6 months as the best clinical procedure to identify a new dentin bridge. However, with our current knowledge of the importance of a bacterial seal of the cavity and the availability of fourth-generation dentin bonding materials, it should be possible to prevent the recontamination of $Ca(OH)_2$-treated exposures. Various studies have shown that other materials used in direct contact with the pulp will produce pulp healing if microleakage is prevented (Bergvall & Brännström, 1971; Brännström & Nyborg, 1977; Bergenholtz, Ahlstedt & Lindhe, 1977; Cox & Bergenholtz, 1984; Cox & others, 1987; Cox, 1987). For those practitioners continuing to use $Ca(OH)_2$ as a pulp-capping material, making certain that microleakage is prevented will assure the long-term success of the pulp-capping procedure.

CONCLUSIONS

This study demonstrates 172 tunnel defects in 192 dentin bridges at a level of 89%. Persistence of blood vessels near the medicament interface during wound healing and new dentin bridge formation appear to be associated with patency of the tunnel defects at all time periods. No internal dentin resorption is present in any teeth with or without tunnel defects. The irregular tunnel defects are associated with the rapid migration of oral contaminants and capping particles into the previously healed pulps, demonstrating the necessity for cavity sealing to prevent recontamination.

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A Suggested Method for Mixing Direct Filling Restorative Gallium Alloy

Y MOMOI • Y ASAMI
M OZAWA • A KOHNO

Clinical Relevance
The handling properties of a gallium-based alloy were significantly improved by the addition of a trace amount of alcohol.

SUMMARY

Good wettability is one of the desirable physical properties of mercury-free gallium-based alloys (Gallium Alloy GF). However, wettability, while providing good adhesion to the cavity wall, has the adverse effect of causing stickiness to the inside of the capsule during mixing, and also to the metal hand instruments used for packing. To control this stickiness the alloy mixture was treated with a small amount of alcohol using two different methods. In both groups (alcohol-added and alcohol-treated groups), 5, 10, or 15 µl of alcohol was added. However, for the alcohol-treated group, the alcohol was shaken from the mixture. In both groups, remarkable improvement was seen in their handling properties, for the alloy mixture did not adhere to the inside of the capsule and was easily taken out as one mass. Compressive strength, tensile strength, and creep were tested in the alcohol-added/-treated groups, and compared with those of a control (conventionally mixed gallium alloy) and a high-copper amalgam (Spherical-D). All tests were done according to ISO 1559 (International Organization for Standardization, 1986), and the results were analyzed using one-way ANOVA (Duncan, $P < 0.05$). Surface microhardness (KHN) and dimensional change during hardening were evaluated according to ISO 1559 and compared to the control results.

In mixing Gallium Alloy GF, an addition of less than 5 µl of alcohol had the effect of preventing the alloy mixture from sticking to the inside of the capsule and remarkably enhanced the handling properties. This suggested mixing technique did not alter either the mechanical properties tested for this material or the desirable dimensional expansion that occurs during hardening.

Tsurumi University, School of Dental Medicine, Department of Operative Dentistry, 2-1-3, Tsurumi, Tsurumi-ku, Yokohama, 230, Japan

Y Momoi, DDS, DDSc, lecturer

Y Asami, DDS, research fellow

M Ozawa, DDS, DDSc, research fellow

A Kohno, DDS, PhD, professor

INTRODUCTION

For many years there has been much work concerned with the potential toxic effects of mercury used in dental amalgam, not only on the human body but also on the environment, provoking much controversy in dentistry today. Consequently, the clinical use of amalgam dropped remarkably in Japan during the last 20 years (Japan Dental Association, 1993). Amalgam, however, still maintains a high popularity among practitioners because of its excellent physical properties and lower technique sensitivity. As an

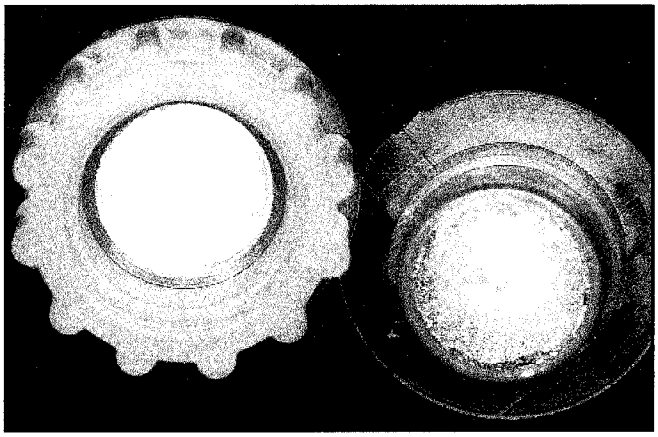

Figure 1. *The gallium alloy sticks to the inside of the capsule after trituration.*

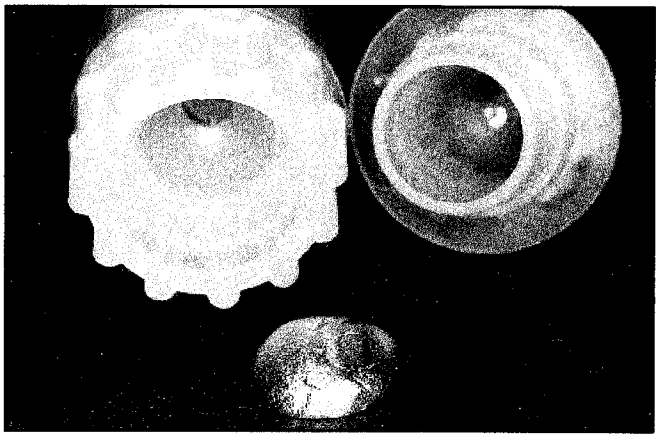

Figure 2. *The addition of alcohol results in the mixture being removed in one mass.*

alternative restorative material for amalgam, a mercury-free gallium-based alloy (Gallium Alloy GF, Tokuriki Honten, Tokyo, Japan) has drawn attention since its market introduction. The physical properties of this material were found to be equivalent to those of amalgam (Horibe, Okamoto & Naruse, 1986; Okamoto, Naruse & Yamamoto, 1992), and its biocompatibility was confirmed in studies on cytotoxicity (Kaminishi & others, 1990a,b; Nakamura & others, 1990) and on pulpal responses after placement (Motokawa & others, 1987; Yoshida & others, 1988).

Gallium alloy is characterized by good wettability. This is one of the desirable physical properties of this material, leading to good adaptation to cavity walls. However, this also has the adverse effect of making the alloy mixture stick to metal instruments as well as to the inside of the capsule during mixing. Mash and others (1993) found that the handling characteristics were significantly more difficult for gallium alloys than for amalgam. After mixing, gallium alloy sticks to the inner wall of the capsule (Figure 1) and consequently is more difficult to remove than amalgam. To control the stickiness of an experimental gallium alloy, Habu and others (1989) used ethanol in mixing, where a mixture of gallium and Ag-Sn-Cu spherical alloy particles were triturated with a small piece of ethanol-soaked sponge. They reported that the ethanol had the effect of reducing the adherence of the mixture to the inside of the capsule. In this study, we added a prescribed amount of alcohol without the sponge to an alloy mixture of Gallium Alloy GF during the mixing procedure, and confirmed that the alloy mixture using alcohol did not stick to the inside of the capsule (Figure 2).

The purpose of this study was to determine the amount of additive alcohol necessary to eliminate the stickiness of Gallium Alloy GF without changing its physical properties.

METHODS AND MATERIALS

The composition of gallium-based alloy used in this study is shown in Table 1. A high-copper amalgam (Shofu Spherical-D, Shofu Inc, Kyoto, Japan) was tested as the control. The alcohol used in this study was ethanol (C_2H_6O, 76.9-81.4 v/v%). All specimens were prepared according to ISO 1559 (International Organization for Standardization, 1986) except the method of mixing the alloy. Cylindrical samples (4 mm in diameter, 8 mm in height) were made for each of two experimental groups (alcohol-added and alcohol-treated) and a control group. For the alcohol-added group gallium alloy was triturated (Almic GF, Tokuriki Honten) at a high frequency for the first 5 seconds, and then the capsule was opened. A prescribed amount of alcohol (5, 10, 15 µl) was then added to the mixture in the capsule using a micropipette. The capsule was then closed, and mixing continued for an additional 5 seconds. For the alcohol-treated group, the alloy was mixed for the first 5 seconds, and ethanol added as for the alcohol-added group. However, immediately after this addition the added alcohol was removed from the capsule by placing a sheet of paper over the open capsule, then shaking the capsule upside down two to three times by hand. In the 10 µl and 15 µl of alcohol-added groups, the amount of alcohol

Table 1. Composition of Gallium Alloy GF (w/w %)

Powder	
Ag	60.50
Sn	24.50
Cu	12.30
Pd	2.70
Liquid	
Ga	65.00
In	18.95
Sn	16.00

Table 2. Compressive Strength (kgf/cm²), Mean (SD), n = 10

Amalgam	3483 (65)	I
Gallium		
control	3434 (89)	I
add 5 µl of alcohol	3475 (102)	I
tr 5 µl of alcohol	3549 (90)	I
add 10 µl of alcohol	3096 (130)	I
tr 10 µl of alcohol	3473 (111)	I
add 15 µl of alcohol	2983 (212)	I
tr 15 µl of alcohol	3188 (293)	I

add (added) = alcohol was added to the alloy mixture.
tr (treated) = alcohol was added and shaken off the alloy mixture.
Means with a line at the same vertical plane were not statistically different at $P < 0.05$.

Table 3. Diametral Tensile Strength (kgf/cm²), Mean (SD), n=10

Amalgam	460 (46)	I	
Gallium			
control	590 (16)		
add 5 µl of alcohol	534 (17)		I
tr 5 µl of alcohol	530 (34)		I
add 10 µl of alcohol	488 (39)	I	I
tr 10 µl of acohol	504 (25)	I	I
add 15 µl of alcohol	458 (40)	I	
tr 15 µl of alcohol	524 (16)		I

add (added) = alcohol was added to the alloy mixture.
tr (treated) = alcohol was added and shaken off the alloy mixture.
Means with a line at the same vertical plane were not statistically different at $P < 0.05$.

removed by shaking was noticeable as a blot of alcohol on a sheet of paper over which the capsule was shaken upside down. The capsule was closed again, and mixing continued for a further 5 seconds. For the control gallium group the alloy was mixed for 10 seconds in a conventional manner according to the manufacturer's instructions. For amalgam the alloy was mixed for 10 seconds according to the manufacturer's instructions, and samples prepared of the same size as those of the gallium samples.

Ten samples from each of the alcohol-added/-treated groups, the control, and the amalgam were tested according to ISO 1559 for compressive strength and diametral tensile strength. For creep testing three samples were tested from each of the 15 µl alcohol-added/-treated groups, the gallium control, and the high-copper amalgam. Surface microhardness was determined for three specimens in each group of 15 µl of alcohol-added, alcohol-treated, control, and amalgam. For the microhardness test the materials were loaded into a cylindrical stainless steel mold (4 mm in diameter, 2 mm in height) and stored in distilled water at 37 °C for 7 days. Before the test, each surface of the samples was finished with successive use of #1500- and #2000 carborundum paper. Microhardness was determined by Hardness Tester (MVK-E, Akashi Corp, Ltd, Tokyo, Japan) at three different points for each surface under a load of 50 grams force (gf) for 30 seconds. All data obtained in this study were analyzed by one-way ANOVA (Duncan, $P < 0.05$). To measure the dimensional change during hardening, one sample for each condition was monitored for 24 hours starting 5 minutes after the end of mixing using an electronic micrometer as described in ISO 1559.

RESULTS

Means and standard deviations for compressive strength are shown in Table 2. There was no statistical difference found in compressive strength between the amalgam, the control, the 5 µl, and 10 µl alcohol-added/-treated groups. All of these strengths were about 3500 kgf/cm². The compressive strength decreased in the 10 µl alcohol-added and 15 µl alcohol-added/-treated groups. Diametral tensile strength is shown in Table 3. The control group showed the highest value, and the 5 µl of alcohol-added/-treated and 15 µl alcohol-treated groups showed larger strength values than that shown for the amalgam group. The values obtained for the creep test are shown in Table 4, where the values

Table 4. Creep (%), Mean (SD), n=3

Amalgam	0.08 (0.02)	I
Gallium		
control	0.08 (0.03)	I
add 15 µl of alcohol	0.08 (0.03)	I
tr 15 µl of alcohol	0.09 (0.01)	I

add (added) = alcohol was added to the alloy mixture.
tr (treated) = alcohol was added and shaken off the alloy mixture.
Means with a line at the same vertical plane were not statistically different at $P < 0.05$.

Table 5. Knoop Hardness Number, Mean (SD), n=3

Amalgam	107.1 (10.3)	I
Gallium		
control	117.0 (4.5)	I
add 15 µl of alcohol	115.4 (0.7)	I
tr 15 µl of alcohol	112.6 (2.6)	I

add (added) = alcohol was added to the alloy mixture.
tr (treated) = alcohol was added and shaken off the alloy mixture.
Means with a line at the same vertical plane were not statistically different at $P < 0.05$.

for the 15 µl alcohol-added/-treated groups were similar to those of the control and amalgam groups. Knoop hardness numbers (KHN) determined in this study are given in Table 5. There was no statistical difference in hardness between the 15 µl alcohol-added/-treated groups, the control, and the amalgam. Dimensional changes (% expansion) observed in single specimens during hardening were as follows: 0.12% for control, 0.11% for 5 µl added-, 0.09% for 5 µl treated-, 0.12% for 10 µl added-, 0.10% for 10 µl treated-, 0.11% for 15 µl added-, and 0.11% for the 15 µl alcohol-treated group. These ranged from 0.09-0.12%. The curve monitored for all gallium samples showed rapid expansion within 1 hour from the start of mixing, which was followed by a gradual increase, reaching an equilibrium 24 hours after mixing. Contraction of the gallium alloy was not seen in any of the conditions throughout the monitored period.

DISCUSSION

A potential solution to avoid the stickiness of the gallium alloy during handling might be to supply the alloy and liquid in a syringe-type PTFE (polytetrafluoroethylene)-coated capsule. However, this method obviously requires additional time and cost for the manufacturer. In view of this, the mixing method suggested in this study is simple and effective. When mixed with alcohol, the mixture of Gallium Alloy GF didn't adhere to the inside of the capsule and was taken out easily as one mass. The required amount of alcohol could be very small, as shown by the results using 5 µl of alcohol. Gallium alloy mixed in a conventional manner resulted in the alloy mixture overlaid on the wall of the capsule, which made removal difficult (Figure 1). When alcohol was added, however, it presumably formed some film on the surface of the alloy mixture that acted as a separating medium between the alloy mixture and the wall of the capsule. Condensing instruments used for packing the alloys used in this study were also found to not stick to the mixture when ethanol was added to the mixtures. The lower compressive and tensile strengths obtained when larger amounts of alcohol were added (10 µl or 15 µl) to the gallium alloys, compared to those of the control, were felt to be due to the alcohol being incorporated into the body of the alloy mixture during trituration.

From the results obtained in this study, it is recommended that not more than 5 µl of alcohol be added to the gallium alloy mixture to avoid the possibility of reducing the physical properties of the resultant alloy mixture. In a clinical setting the addition of less than 5 µl of alcohol could be done by submerging the head of cotton pliers into alcohol liquid in a glass dish, then transferring one drop of the liquid to the alloy capsule.

The minimum compressive strength requirement for amalgam at 24 hours after mixing is 300 MPa (ISO 1559). The compressive strength of gallium alloy obtained in this study fulfilled this requirement in all conditions except the 15 µl alcohol-added category. The gallium alloy showed greater diametral tensile strength values than that of amalgam except for the 10 µl alcohol-added/-treated and 15 µl alcohol-added groups. In the strain-stress curves obtained from strength measurements, gallium alloy showed a lower flexural modulus than amalgam; consequently the gallium alloy is considered to be a less brittle and more resilient material than amalgam. Den, Fujii, and Machida (1991) reported less marginal breakdown with Gallium Alloy GF than with amalgam in their long-term clinical observation of class 1 and 2 restorations in young patients. The creep values showed rather large standard deviations, and there was no statistical difference between the 15 µl of alcohol-added/-treated, control, and amalgam groups. However, the creep values were all very small compared to the acceptable value for amalgam in ISO 1559 (maximum of 3%). The values determined in this study agree well with those found by Okamoto and others (1992). The Knoop hardness of Gallium Alloy GF after 7 days of water storage was almost the same as that for amalgam, the control, and the 15 µl of alcohol-added/-treated conditions. Creep and hardness were not tested in the 5 µl and 10 µl alcohol-added/-treated conditions. From the results obtained, the creep and hardness values for the 5 µl and 10 µl alcohol-added/-treated conditions ranged between the two extremes, the control and 15 µl alcohol-added conditions. Results indicate that the gallium alloy mixed with less than 5 µl of alcohol might be as strong as amalgam, thus strong enough to be placed in a stress-bearing site in the mouth. Okamoto and others (1992) showed a good relationship between hardness and dimensional change in Gallium Alloy GF 24 hours after mixing, and stated that both properties reached an equilibrium within the first 60 to 90 minutes. Dimensional change (% expansion) during hardening of gallium alloy in all conditions ranged from 0.09 to 0.12%, which meets the standard value proposed by ISO 1559 for dental amalgam (-0.1% to 0.2%). The dimensional change of gallium samples showed rapid expansion within the first hour, followed by a more gradual increase, reaching an equilibrium at 24 hours after the start of mixing. No shrinkage was observed through the testing period, while in amalgam there is often an initial contraction. During the setting reaction, Ga has an affinity for Pd and In for Ag, which results in the development of the $PdGa_5$ and In_4Ag_9 intermetallic compounds respectively. These reactions contribute to an

expansion of gallium alloy during hardening (Okamoto & others, 1992), which may give gallium restorations an advantage over amalgam by providing better marginal adaptation during hardening.

Oshida and Moore (1993) investigated anodic polarization of gallium alloys in Ringer's solution and suggested that the gallium alloy was more corrosion-prone than that of a high-copper amalgam. Further investigation is needed to determine the corrosion potential of adding alcohol to a gallium alloy mixture.

CONCLUSION

In mixing Gallium Alloy GF, an addition of a small amount of alcohol—less than 5 µl—effectively controlled the stickiness of the alloy mixture, thereby allowing the triturated mixture to be removed in one mass from the capsule. Addition of this small quantity of alcohol didn't significantly change the mechanical properties of compressive strength, diametral tensile strength, creep, hardness, or setting expansion/contraction.

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A Review of Polymerization Contraction: The Influence of Stress Development versus Stress Relief

R M CARVALHO • J C PEREIRA
M YOSHIYAMA • D H PASHLEY

Clinical Relevance
Understanding the principles that may interfere with ideal bonding of resins to dentin is necessary to provide clinicians the opportunity to improve the quality of their restorations.

SUMMARY

The insertion of bonded resin composites into cavity preparations leads to a competition between polymerization contraction forces and the strength of bonds to tooth structure. The degree of stress development can be controlled, to some extent, by the cavity design (C-factor), the use of bases, the size, shape, and position of increments of composite resins placed in the cavity, and whether the resin is light- or chemically cured. Stress relief can be accomplished by maintaining the C-factor as low as possible, using chemical-curing resins, low modulus liners, and, over time, by water sorption. A thorough understanding of these principles permits clinicians to exercise more control over these variables, thereby improving the quality of their bonded restorations.

Medical College of Georgia, School of Dentistry, Department of Oral Biology-Physiology, Augusta, GA 30912-1129

R M Carvalho, DDS, PhD, assistant professor, Bauru School of Dentistry USP, Department of Operative Dentistry, Bauru, SP, Brazil

J C Pereira, DDS, PhD, associate professor, Bauru School of Dentistry USP, Department of Operative Dentistry, Bauru, SP, Brazil

M Yoshiyama, DDS, PhD, assistant professor, Tokushima University, School of Dentistry, Department of Conservative Dentistry, Tokushima, Japan

D H Pashley, DMD, PhD, regents' professor

INTRODUCTION

Modern advanced technology continues to develop improved resin composites. As a result of this, new resin composites have become widely used for many purposes in restorative dentistry. Although they are considered the best aesthetic direct restorative material (Erickson & Glasspoole, 1994), existing drawbacks include inferior wear resistance to that of amalgam, excessive polymerization shrinkage, incomplete conversion and cross-linking, and undesirable water-sorption (Ferracane, 1993). The strength of the resin composites is basically dependent upon monomer composition, filler content, and degree of conversion and cross-linking of the resulting polymer. Resin composites are made stronger when BIS-GMA molecules are employed as the main monomer. The degree of conversion can be maximized by including a high percentage (40-50%) of diluents (TEGDMA) in the resins (Ferracane, 1989), but this is accompanied by significant polymerization shrinkage (1.5-3 vol%, de Gee, Feilzer & Davidson, 1993). The polymerization shrinkage of a resin composite can create contraction forces that may disrupt the bond to cavity walls. This competition between the mechanical stress in polymerizing resin composites

and the bonds of adhesive resins to the walls of restorations is one of the main causes of marginal failure and subsequent microleakage observed with resin restorations (Davidson, de Gee & Feilzer, 1984). Microleakage, leading to secondary caries, has been reported as the predominant reason for replacement of composite resin restorations (MacInnis, Ismail & Brogan, 1991; Qvist, Qvist & Mjör, 1990). The amount of stress generated during polymerization of resins is related to the restriction of polymerization shrinkage (Bowen, Nemoto & Rapson, 1983; Davidson & de Gee, 1984). Restricted shrinkage occurs on bonded surfaces; unrestricted shrinkage occurs on free, unbonded surfaces. Under conditions of marginal dentin bonding, only in restorations where the flow of shrinking resin composite can relieve a great part of the stresses developed during polymerization will the bond be preserved (Davidson & de Gee, 1984). According to Davidson (1986), the degree of resin flow will be determined by the material and the ratio of the free, unbonded surface to the bonded surface area of the restoration. The flow capacity of a resin composite and the resultant mechanical stress on bonded surfaces can be influenced by several factors that will be reviewed below.

GENERATION OF STRESSES IN DIFFERENT CAVITY CONFIGURATIONS (C-FACTOR)

Davidson and others (1984) reported the influence of contraction stresses, generated during polymerization shrinkage, on adhesion of light-cured and chemically cured resin composites to dentin, in both two-dimensional and three-dimensional models. In the two-dimensional model, the bond strength could withstand the contraction forces because the adhesion of the resin composite was performed on a flat dentin surface. This configuration allowed a large, free, and unbonded surface, which permitted the flow of the resin across the free surface during its polymerization shrinkage, thereby minimizing stresses at the bonded surface. In the three-dimensional cavity model, the composite was bonded to two or more cavity walls. In such situations, the resin flow was limited or restricted, leading to an increase in the stress generated at bonded surfaces. It has been shown that some adhesive systems produced lower bond strengths to dentin when applied to three-dimensional cavities, thereby increasing the ratio of bonded versus unbonded area and reducing the capacity of the resins to flow (Haller & others, 1991; Prati & others, 1992). In a complex cavity preparation restored with adhesive systems and resin composite, the marginal integrity of the restoration is limited by the weakest bond. For instance, in a two- or three-surface cavity surrounded by acid-etch enamel, the contraction stresses that develop during polymerization of the resin may cause rupture of a cementum bond (which is usually weaker than enamel bonds) somewhere around its peripheral limits, which is often at the gingival floor of an approximal box, where the thickness of enamel is minimal. This may permit bacteria to colonize the dentin surface and shed products into the dentin that may irritate the pulp. The marginal seal can generally be preserved around a class 1 cavity preparation wherever circumferential acid-etched enamel is present because of the stronger adhesion achieved to enamel. However, the dentin bond to the pulpal floor may fail because bonds to deep dentin are often weaker than enamel bonds. The clinical consequences of this are less serious, because the gap created by the failed bond to the pulpal floor does not communicate with the oral cavity (Mitchem, 1988). However, patients may feel postoperative sensitivity whenever they bite on the restoration due to the compression of the fluids in the fluid-filled gap between dentin and resin or due to flexure of the resin composite under occlusal loads.

The role of cavity configuration (C-factor) on the development of polymerization stresses with a resin composite was demonstrated by Feilzer, de Gee, and Davidson (1987). They described an in vitro model in which the curing stress of a resin composite could be related to the configuration of the restoration. That is, if the cohesive failure of the materials is disregarded and the cavity walls are considered rigid, the only source available to relieve the stresses of polymerization contraction is the elastic deformation of the material and the flow from free, unbonded

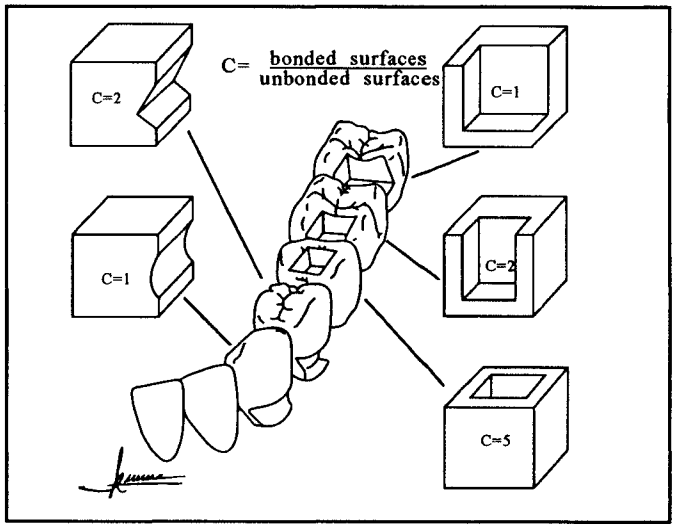

Figure 1. *The stress generated in different cavity designs is proportional to the configuration (C-factor) of the cavity. The C-factor is the ratio of bonded to unbonded surface areas. The smaller the C-factor, the less the competition between the strength of the bond and the forces of polymerization contraction. The most unfavorable C-factor is found in bulk-filled class 1 cavities.*

surfaces. Therefore, the model can be expressed as a ratio between the bonded and unbonded surfaces:

$$C = \frac{\text{total bonded area}}{\text{total unbonded area}}$$

Figure 1 illustrates the application of the C-factor to several cavity designs in a clinical situation. Generally, the less the free, unbonded area there is in a cavity, the less will be the ability of resin to flow, and therefore the greater will be the contraction stress at the bonded surfaces. The C-factor values can be interpreted from a clinical point of view as follows: In general, class 2 and class 3 composite restorations achieve C-factors in the range of 1.0-2.0 when bulk filled. By filling the box-like cavities regionally, in several increments, the clinician can greatly lower the effective C-factor of the preparation. Shallow class 5 composite restorations have almost as much free surface as bonded surface and hence have C-factors less than 1. Thus it is desirable, from a shrinkage perspective, to avoid creating box-like class 5 cavities. According to the results of Feilzer and others (1987), restorations with $C<1$ are the only ones likely to survive polymerization contraction stresses. When $C>1$, the results are unpredictable under clinical situations. All of this is due to the fact that the stress generated by polymerization contraction has been reported to be about 13-17 MPa (Davidson & others, 1984; Feilzer, de Gee & Davidson, 1993), which is higher than many dentin bond strengths. For instance, if one employed a chemically cured adhesive system that developed a bond strength to dentin slowly rather than immediately, and placed a light-cured resin composite over it, the fast-curing composite might generate an immediate high contraction stress before the dentin bond strength achieved a value that could overcome this stress. Generally, bond strengths of adhesive resins to dentin are evaluated after a minimum of 24 hours. The clinical performance of adhesive systems can be better evaluated by measuring their long-term bond strengths to dentin, which are reported to be lower after periods of weeks or months when compared to the bond strengths achieved after 24 hours (Retief & others, 1988; Burrow, Tagami & Hosoda, 1993). However, with regard to polymerization contraction, early bond strengths are crucial, because they will be responsible for preserving the bond when the stresses arising from polymerization contraction are developing. Few papers have attempted to measure the very early bond strength of adhesive systems to dentin (Komatsu & Finger, 1986; Finger & Ohsawa, 1987; Retief & others, 1993). The bond strength of some resin systems to dentin tend to increase significantly from the first minutes after bonding to 24 hours. This is because chemically cured resins have a slow process of curing. Even light-cured resins undergo significant postirradiation polymerization after exposure to the light source (Leung, Fan & Jonston, 1983). A complete cure of the resin is necessary to achieve its maximum mechanical strength and therefore provide higher bond strengths. The mechanical characteristics of a resin composite, measured close to the bonded interface with dentin, have been shown to be strongly correlated with the shear forces necessary to disrupt that bond (Yanagawa & Finger, 1994). That is, the higher the mechanical properties of the resin composite, which can be better achieved when it is properly light cured, the higher the bond strength. Even though current adhesive resins may generate high bond strength to dentin (ca 20-30 MPa, Sano & others, 1994; Carvalho & others, 1994), this is usually obtained after 24 hours of bonding onto flat dentin surfaces where the C-factor is low. If the same resins could be tested immediately after bonding in a 3-D cavity configuration, the bond strengths would probably be much lower. If a small fraction of the bond is broken during polymerization contraction of the resins, the retention of the resin composite may not be significantly affected; however, the seal of the restoration is compromised and may lead to undesirable clinical consequences. This hypothesis may also explain the lack of a good correlation between bond strength and marginal leakage data (Prati & others, 1990; Retief & others, 1992). To achieve good dentin bonding, the forces of polymerization contraction must be minimized and dentin bond strengths must be maximized.

ROLE OF CURING CHARACTERISTICS OF RESIN COMPOSITES IN STRESS DEVELOPMENT

Restorative resin composites can be either chemically or light activated. The mode of cure for these two types of resins is different and was hypothesized to influence the flow capacity of the resin (Krejci & Lutz, 1991). Light-cured resin composites undergo an immediate and rapid polymerization reaction that permits less resin flow than chemically cured resin composites, because they do not exist in a gel stage for very long. Theoretically, the lower the capacity to flow, the greater will be the contraction stress, which can be decisive for the success of a bonding procedure. In fact, it has been demonstrated that light-cured resin composites generate higher polymerization shrinkage stresses than the analogous chemically cured composites (Feilzer & others, 1993). Under the same C-factor, the behavior of two resin composites regarding the development of stress as a function of time are shown in Figure 2.

The chemically cured resin composites are more porous due to the incorporation of air bubbles during mixing. The presence of air bubbles

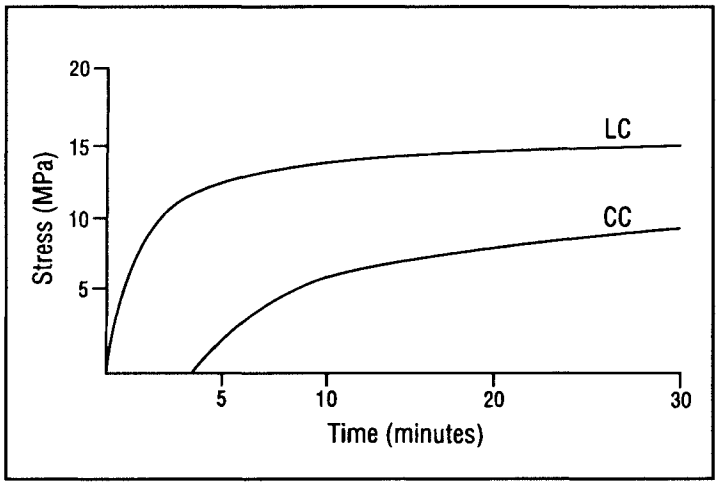

Figure 2. *Stress generated in different curing modes of resin composites of the same C-factor (C = 1). LC = light-cured; CC = chemically cured. Adapted from Feilzer and others (1987).*

increases the internal free, unbonded surface area, which permits more resin flow during polymerization, thereby decreasing the contraction-induced stress (Krejci & Lutz, 1991; Feilzer & others, 1993). It has been shown that the stress relief in thin resin layers is proportional to the amount of porosity in the resin. The presence of oxygen in the air voids also contributes to the stress reduction (Alster & others, 1992). The role of air incorporation in the stress relief of resin composites is important, since increasing the volume of air bubbles in a resin composite by 5% can reduce the stress level by approximately 50%. This is thought to be due to the enlargement of the bubbles or voids during contraction stress up to 10% of their original diameter (Alster & others, 1992). Although it seems possible to counteract the destructive curing stress by admixing porosity to the resin composites, one should keep in mind the negative effect of porosities on the mechanical properties of the resin (de Gee, 1979). The presence of oxygen-inhibited areas within the bonding resin may interfere with the quality of the bond. Excessive air thinning of a bonding agent can result in oxygen inhibition of the polymerization of the adhesive layer, reducing the cure and lowering the bond strength (Glasspoole & Erickson, 1992; Erickson & Glasspoole, 1994). Before the intentional incorporation of air in resin composite restorations can be recommended, further research needs to be done.

ROLE OF WATER SORPTION IN STRESS REDUCTION

Resin composites as organic materials are subjected to water sorption. Once a resin restoration is exposed to water, it may absorb the solvent into the restoration, causing a volumetric expansion that partially compensates for polymerization contraction. Several groups have shown that the gradual expansion of the material may restore marginal seals opened by polymerization shrinkage (Hirasawa & others, 1983; Fan & others, 1985; Soltesz, Bath & Klaiber, 1986). However, clinically this process is complex and also depends upon the configuration of the restoration. Bonded surfaces shrink differently from unbonded surfaces. Similarly, water sorption will vary with cavity design and resin volume. Polymerization contraction is rapid and occurs during curing, while the water expansion is a slower process that may take days. Thus, bacterial colonization of open margins may occur before they partially close. The stress relaxation by water sorption may vary from one type of resin to another. The hydrophobic and saturated nature of tricyclodecane dimethacrylate-based resin (Visio Fil, Visio Molar, ESPE, GmbH, Seefeld/Oberbay, Germany) permits very little hygroscopic relaxation when compared to the more hydrophilic BIS-GMA/TEGDMA-based resins (Silux, 3M Dental Products, St Paul, MN 55144). On the other hand, water sorption may cause erosion of the filler/matrix interface and softening of the polymer network. This may lead to reduction in strength, stiffness, and wear resistance (Söderholm & others, 1984; Ferracane, Hopkin & Condon, 1993). To minimize these problems, more hydrophobic monomers such as the ethoxylated version of BIS-GMA (BIS-EMA) have been evaluated (Ruyter & Nilsen, 1993). However, the stress relaxation of these resins by water sorption is expected to be lower. The type of filler and the percent filler loading also play a role on the degree of water sorption and subsequent stress relaxation of a resin (Calais & Söderholm, 1988). The higher the concentration of organic matrix in a composite resin, the higher will be the tendency for water sorption. Shrinkage can be reduced but not eliminated by increasing the filler loading. In a clinical situation, the volume of the restoration and its accessibility to water (Feilzer & others, 1989) are decisive in determining the degree of stress relaxation that is achieved. Resins used as luting agents offer a small surface to the oral fluids and also a long pathway for water diffusion. In such cases, the C-factor is theoretically extremely high, indicating the potential for causing higher stress and much lower stress relaxation due to water sorption. This is particularly applicable to luted indirect resin composite and cast ceramic restorations. On the other hand, the potential for marginal defects with these restorations may be minimized by using dual-cure resin-luting cements (Lutz, Krejci & Barbakow, 1991). The thinness of these luting resins tends to reduce the forces of

polymerization shrinkage because of their small volume, and their relatively slow polymerization allows more time for stress relaxation due to resin flow.

SOLUTIONS TO THE PROBLEM

There are several solutions to the competition between the bond strength of resins to dentin and the forces of polymerization contraction. One approach is to develop dentin bonding agents that are able to develop immediate bond strengths that are greater than those developed by polymerization contraction and are equal to those obtained to acid-etched enamel. Under such conditions, the dentin bond strength could withstand the stresses of polymerization shrinkage and all margins and bonds would remain intact. A second solution is to cover the bonded dentin surfaces with an elastic cavity liner. This acts as a "shock-absorber" and places a low modulus material between the relatively rigid dentin and resin composite (Kemp-Scholte & Davidson, 1990). Abdalla and Davidson (1993) recently reported on the bond strength and microleakage of three of the most-recent-generation bonding systems (Scotchbond MP, 3M; Clearfil Liner Bond System, Kuraray, Osaka, Japan; Optibond, Kerr Mfg Co, Romulus, MI 48174). The latter two systems include an intermediate resin liner that is placed between the bonded dentin and the resin composite. Not only were the bond strengths near 17 MPa, but the microleakage of these systems was virtually zero even after thermal and mechanical stressing. The resin interdiffusion zone generated as the main bonding mechanism of most of the current dentin bonding systems may also function as a stress relaxation layer, since it has a lower modulus than the underlying mineralized dentin (Van Meerbeek & others, 1993).

A third solution is to insert resin composites in increments to reduce the volume of the resin that is shrinking during polymerization. The use of reduced amounts of resin to be polymerized at each increment has been shown to reduce the stresses generated to the cavity walls (Lutz & others, 1991). A three-sited light-cure technique has been proposed to efficiently reduce the contraction stresses during class 2 resin composite fillings (Krejci, Sparr & Lutz, 1987). It is generally accepted that light-cured resin composites shrink toward the direction of the light source. Therefore, the application of the light source may be strategically located to direct the shrinkage of each increment towards the cavity walls. Interproximal and cervical cure-through matrices are available and might be used as a tool to direct and counteract polymerization shrinkage. Although all of this may contribute to the results, ultimately, incremental filling techniques actually lower the C-factor to below 1, since there is usually almost as much free surface as bonded surface in any single increment. Recently, a technique has been described to minimize the effects of resin shrinkage on marginal sealing (Bertolotti, 1991). In this technique, the approximal box is filled with a chemically cured resin composite and the occlusal portion filled with a light-cured resin composite. The rationale is that certain adhesives may initiate the cure of the self-cure composite at the interface, causing the polymerization contraction to occur toward the dentin surface instead of away from the cavity walls (Bowen, Cobb & Rapson, 1982; Imai & others, 1991). The use of a light-cured resin on the occlusal portion of the restoration permits the clinician complete control of the working time and surface characteristics. If the early bond strength of the adhesive to dentin is high, the slower polymerizing chemically cured resin may serve as a stress-breaker for the overlying light-cured resin composite without any adverse effects. However, there have been no controlled laboratory or clinical trials to demonstrate the superiority of this restorative technique over more conventional methods.

Several research groups are attempting to develop new resin composites that do not shrink when they polymerize (Eick & others, 1993). Spiro-orthocarbonate monomers have been synthesized that expand during polymerization through a double ring-opening process (Stansbury, 1992). Further improvements are being developed to cause sufficient double ring-opening to generate enough expansion to overcome the shrinkage generated by conventional dimethacrylates. The commercial development of these resins is many years away. However, if such resins can be developed, they would largely eliminate the clinical consequences of polymerization contraction and permit simple bulk filling of cavity preparations. The use of glass inserts (Bowen, Eichmiller & Marjenhoff, 1991) or prepolymerized balls of resin composite both minimize the volume of resin that shrinks during polymerization. This reduces the forces of polymerization contraction (Donly & others, 1989). The rationale for this relies on the fact that fillers in the resin composites do not shrink, hence, the higher the amount of fillers in one resin composite, the smaller would be the shrinkage. This has led to the erroneous belief that microfilled resin composites shrink more than hybrid materials because of the lower amount of filler. However, it has been recently shown that both microfilled and hybrid resin composites shrink about the same (ca 3%) during polymerization (Erickson & Glasspoole, 1994). This is because the filler particles also consist of prepolymerized microfilled material so that total volume of filler is not very different between many hybrid and microfilled resin composites.

Finally, the application of zinc phosphate, polycarboxylate cement, or calcium hydroxide-containing bases to the internal walls of cavities can theoretically change the C-factor of the cavity, because the adhesive resins do not bond to these surfaces, making them equivalent to a free or unbonded surface even though they are internal surfaces. Thus, even though a box-type class 1 cavity would theoretically have a very high (and undesirable) C-factor because it would have five bonded walls and only one unbonded or free surface (Figure 1), basing the pulpal floor would produce two free surfaces and four bonded surfaces. While such procedures would decrease polymerization stresses, they would also decrease the bonded dentin surface area and perhaps decrease the retention of such restorations and increase the risk of microleakage. This might become a problem if one based both the pulpal and axial walls of a class 2 restoration, leaving too little bonded dentin for retention and sealing of the peripheral margins of the restorations. It would be desirable to evaluate the effects of different C-factors in a 3-D cavity model on the bond strength of resin composites to dentin. The use of glass-ionomer bases under composite resin restorations has also been demonstrated to reduce the stresses generated at the cavity walls during polymerization (Lutz & others, 1991).

CONCLUSIONS

The setting stress of resin composites and bonding agents under clinical situations is much more complex than was previously thought. The high values of contraction stress reported in some studies for specific configurations of restorations may overcome the bond strengths of resins to dentin. This might explain the large number of bond failures and gap formation frequently observed in studies with bonding agents. However, there are a number of phenomena and procedures that can reduce the forces of polymerization contraction. The clinical success of bonded resin composite restorations is largely affected by these phenomenon, which can be manipulated to some extent by clinicians to therapeutic advantage.

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A Clinical Evaluation of the Electric Pulp Tester as an Indicator of Local Anesthesia

A J CERTOSIMO • R D ARCHER

Clinical Relevance
The electric pulp tester can be used as a valuable tool to effectively predict the level of anesthesia prior to the initiation of an operative (restorative) procedure.

SUMMARY

Local anesthesia is the primary method in dentistry to control patients' pain. However, several studies have shown that profound anesthesia is not always achieved. The electric pulp tester has been used to measure the level of local dental anesthesia during endodontic therapy. However, no study has been performed that evaluates the ability of the electric pulp tester to predict the efficacy of local anesthesia prior to an operative procedure. If ineffective anesthesia could be predicted, supplemental injections could be administered to alleviate the anesthetic problem. The purpose of this study was to evaluate the ability of the electric pulp tester to measure the level of local anesthesia prior to operative treatment.

The study was performed in vivo on patients requiring operative therapy. All teeth were pulp tested preoperatively for vitality using the electric pulp tester. After injection of local anesthesic, traditional parameters of dental anesthesia were verified (lip numbness, mucosal sticks). Teeth were then retested with the electric pulp tester and the results recorded. The teeth were then prepared for restoration using conventional instrumentation, and the patient's level of anesthesia evaluated using a visual analog scale. The electric pulp tester readings were compared to the patient's responses using Fisher's Exact test (two-tail). The results indicate that the electric pulp tester can be a valuable tool in predicting potential anesthetic problems in operative (restorative) dentistry.

Naval Dental Center, Advanced Clinical Program, Norfolk, VA 23511

Alfred J Certosimo, DMD, director

Richard D Archer, DDS, private practice, Virginia Beach, VA

INTRODUCTION

In the practice of dentistry, local anesthesia has been the primary method of controlling patient pain during clinical procedures. The basic criteria for success of local anesthetic injections is the absence of pain during these procedures. However, research has shown that this profound level of anesthesia is not always achieved (Northrop, 1949; Kaufman, Weinstein & Milgrom, 1984; Bjorn, 1947). Kaufman and others (1984) surveyed 93 general dentists and found 90% had reported some anesthesic failure during restorative visits during the previous 5 days. They found an average failure rate of 13.1%, ranging from 0% to 48.6%. Forty-seven percent of the patients who did not experience numbness were reported fearful or anxious. Fiset and others (1985) provide an excellent review of patients' psychophysiological responses to dental injections and inadequate dental anesthesia. Such studies clearly indicate that lack of profound local anesthesia is a meaningful clinical problem.

Dentists have long used subjective soft tissue signs

(lip and soft tissue numbness) as indicators of local anesthesia with varied success (Kaufman & others, 1984). These subjective signs are further complicated by the patient's interpretation of pain, which is highly variable and depends on emotional and physiological states and past experiences (Harris, 1956; Topazian, 1957). However, studies by Bjorn (1947) and Harris (1956) found that the electric pulp tester gave a more precise and objective measurement of local anesthesia. McDaniel, Rowe, and Charbeneau (1973) reported that prolonged electric pulp testing caused no histological damage to the dental pulp. Therefore, the electric pulp tester provides a safe and effective method of evaluating dental anesthesia.

Dreven and others (1987) evaluated the electric pulp tester as a measure of anesthesia prior to endodontic procedures and found it to be accurate in evaluating local anesthesia in teeth with uninflamed pulps. To date, no study has evaluated the electric pulp tester's ability to predict potential pain during dental restorative procedures. The purpose of this study is to evaluate the electric pulp tester's ability to predict the level of anesthesia prior to restorative procedures. If proven effective, the electric pulp tester could predict potential anesthetic problems that may be avoided through the use of supplemental anesthetic injections. This would result in lower levels of patient anxiety and higher patient acceptance.

METHODS AND MATERIALS

One hundred thirty-eight teeth from 138 patients (86 male, 52 female), ranging in ages from 18 to 64 years old, at the Portsmouth Naval Hospital Dental Clinic were used in this study. All subjects were in good health and were not taking any medications that would alter pain perception, as determined by a written health history and oral questioning. The subjects had no contraindications to 2% lidocaine with 1:100,000 epinephrine or to the injection technique being used.

A clinical examination with an explorer and periodontal probe was performed on all prospective teeth to be considered in this study. Teeth with large restorations, full or partial cast coronal restorations, restorations with poor margins, previous endodontic therapy, or periodontal disease were eliminated from the study.

Clinical and radiographic examinations determined the presence of caries in maxillary and mandibular molars, premolars, and anterior teeth more than one millimeter from the pulp (Reeves & Stanley, 1966); no history of pain or sensitivity; no signs of periapical pathosis; and no periodontal disease.

An Analytic Technology electric pulp tester (model 2001; Analytic Technology Corp, Redmond, WA 98052) was used experimentally to test vitality and analgesia (Dreven & others, 1987). This digital, electric vitality scanner, with lip clip to complete the circuit, was used for all pre- and postinjection testing. The rate of current increase was kept constant throughout the study. The elapsed time from zero to the highest reading (80/80) was 25 seconds. Nickel-cadium batteries were used and recharged after each day's use. All testing was performed by trained personnel.

All pulp testing was performed in the same manner. The investigator and trained personnel wore sterile latex examination gloves. Pre-operative baseline vitality measurements were performed on the teeth to be tested. All teeth were isolated with cotton rolls and then air dried. A small amount of Crest toothpaste (Procter & Gamble, Cincinatti, OH 45202) was used as the electrolyte between the electrode tip of the electric pulp tester and the tooth to be tested. The probe was positioned on sound enamel on the incisal or occlusal two-thirds of the facial or buccal surface of the teeth (Jacobsen, 1984). The probe tip was positioned so that it did not contact the gingiva, restoration, or enamel cracks. The testing of each tooth started upon contact of the electrode to the tooth and terminated when the subjects raised their hands to indicate feeling the initial sensation in the tooth. If the subject felt nothing, even at the maximum value of 80/80, the test was stopped and the tooth was not included in the study.

Anesthesia was administered by giving two cartridges (3.6 ml) of 2% lidocaine with 1:100,000 epinephrine (Novocol Pharmaceutical Inc, Dover, DE 19901) using a standard dental aspirating syringe. In the mandible, the inferior alveolar technique, as described by Monheim (Bennett, 1974) and modified by Hayden (Jorgenson & Hayden, 1972) was used. An additional one-fourth of a cartridge was injected for anesthesia of the long buccal nerve. Maxillary molars and premolars received one cartridge by

Table 1. Location of Pain by Tooth

PAIN LEVEL	Mandibular Anterior	Mandibular Posterior	Maxillary Anterior	Maxillary Posterior	TOTAL
0 (NONE)	4	34	15	56	**109**
1 (MILD)	4	8	0	3	**15**
2 (MODERATE)	10	4	0	0	**14**
3 (SEVERE)	0	0	0	0	**0**
TOTAL (138)	18	46	15	59	**138**

Table 2. Location of Pain by Tooth

Pain Type		Mandibular Anterior	Mandibular Posterior	Maxillary Anterior	Maxillary Posterior	TOTALS
0	Frequency	4	34	15	56	109
	Percent	2.90	24.64	10.87	40.58	78.99
	Row Percent	3.67	31.19	13.76	51.38	
	Column Percent	22.22	73.91	100.00	94.92	
1	Frequency	4	8	0	3	15
	Percent	2.90	5.80	0.00	2.17	10.87
	Row Percent	26.67	53.33	0.00	20.00	
	Column Percent	22.22	17.39	0.00	5.08	
2	Frequency	10	4	0	0	14
	Percent	7.25	2.90	0.00	0.00	10.14
	Row Percent	71.43	28.57	0.00	0.00	
	Column Percent	55.56	8.70	0.00	0.00	
	COLUMN TOTALS	18	46	15	59	138
		13.04	33.33	10.87	42.75	100.00

the posterior superior alveolar injection technique and one cartridge by infiltration (Bennett, 1974). In addition, a palatal infiltration (0.2 to 0.3 ml) was given.

After injection of the anesthetic agent, a waiting period of 5 minutes for maxillary teeth (Mikesell & others, 1987) and 15 minutes for mandibular teeth (Vreeland & others, 1989) was observed prior to evaluating each patient for subjective signs of clinical anesthesia. These times were reported by Mikesell and others (1987) and Vreeland and others (1989) as the optimum time required to achieve profound anesthesia in the respective arches. The subjective signs consisted of facial gingival anesthesia on maxillary teeth and lower lip numbness on the anesthetized side for mandibular teeth (Harris & Blockus, 1952). The presence of subjective soft tissue signs is currently the standard of care in evaluating the onset of local dental anesthesia (Dreven & others, 1987). If no subjective signs of anesthesia appeared within the respective time intervals, 1.8 ml of 2% lidocaine with 1:100,000 epinephrine was readministered and the appropriate waiting times, as initially described, were observed. Once subjective signs of anesthesia appeared, the tooth to be restored was then tested for analgesia using the same electric pulp test procedure as was used to record baseline readings, and the results were recorded. If no subjective signs of anesthesia appeared, the patient was disqualified from the study. These teeth were given supplemental anesthetic injections using the periodontal ligament technique (Walton & Abbott, 1981) and restored using standard operative dentistry techniques.

When subjective signs of anesthesia appeared and electric pulp tester measurements were recorded, the clinical restorative procedure was started. In order to limit clinical variables, one clinician performed the restorative procedures on all teeth involved in this study. The teeth were isolated with a rubber dam and standard conservative cavity preparation was executed according to procedures described by Sturdevant and others (1985). Each patient was asked to rate the sensations they perceived during the restorative procedure using a visual analog scale (Table 1). The ratings were: 0 = no pain; 1 = mild pain (pain that is uncomfortable but bearable); 2 = moderate pain (pain that is very uncomfortable, difficult to bear, and requires more anesthetic to overcome the pain); and 3 = severe pain (pain that is severe, impossible to bear, and requires more anesthetic to overcome the pain). If the patients felt unbearable pain during the operative procedure, they were provided supplemental anesthesia using the periodontal ligament injection (Walton & Abbott, 1981). The periodontal ligament injection was given on the mesial and distal of the experimental tooth using a 30-gauge ultrashort needle and 2% lidocaine with 1:100,000 epinephrine in a standard aspirating syringe. Conservative outline form was achieved, appropriate bases placed where indicated, and the tooth restored using standard amalgam or composite procedures.

Data were analyzed by statistically comparing pain ratings to electric pulp test readings after the administration of local anesthesia. Pain ratings from the visual analog scale were compared to soft tissue signs.

The Fisher's Exact Test (2-tail) was determined an appropriate statistical instrument to be used in this study. It is a form of the chi-square analysis that only evaluates the *P* value. It is a four-cell matrix

Table 3. Tooth Location Pain vs Pulp Tester Readings

	MANDIBULAR		MAXILLARY	
Frequency Pain %	Anterior	Posterior	Anterior	Posterior
80/80 No Pain	4 22%	34 74%	15 100%	56 95%
Non-80/80 Mild/Moderate Pain	14 78%	12 26%	0 0%	3 5%
	18	46	15	59
COLUMN TOTALS	64		74	
	138			

system that is particularly valuable when there are cells with less than five subjects.

RESULTS

The results of the level of pain by tooth location are shown in Table 1. Of the 138 operative procedures performed in this investigation, subjects experienced no pain (pain rating 0) in 109 teeth (79%). Subjects reported mild pain (pain rating 1) in 15 teeth (11%) and moderate pain (pain rating 2) in 14 teeth (10%). No subjects experienced severe pain (pain rating 3).

Table 2 demonstrates that levels of pain during operative procedures were consistently higher in mandibular anterior teeth than all other tooth groups, in all pain levels evaluated: mild, moderate, and mild + moderate. All anesthetic problems requiring re-injection (moderate pain rating 2) involved mandibular teeth. Furthermore, the mandibular anterior teeth had a significantly higher rate of anesthetic problems (mild + moderate pain) than all other teeth. This is illustrated in Table 3: mandibular anterior (78%), mandibular posterior (26%), maxillary posterior (5%), maxillary anterior (0%). The Fisher's Exact Test (2-tail) 5.98^{-10} with a P value of < 0.00001 indicated that there is only one chance in 100,000 that the results could occur by chance. Alternatively stated, there is a greater than 99% probability that our results are accurate, and that the mandibular anterior teeth are the most difficult to anesthetize, followed by the mandibular posterior, maxillary posterior, and maxillary anterior. It should be noted that there were no anesthetic failures in the maxillary anterior teeth. Collectively, the results of our data clearly indicate that the electric pulp tester can accurately predict the level of local anesthesia.

Table 4. Pain/No Pain vs Response

	Pain	No Pain
80/80 No Response	5	104
<80 Response	29	0

Table 4 shows the "no response" at 80/80 versus the response before 80 relative to pain during the procedure and no pain during the procedure. The five responses in the pain versus 80/80 "no response" column represent a false-positive recording and are addressed in the discussion section.

The Fisher's Exact Test (2-tail) was determined an appropriate statistical instrument because it is a four-cell matrix system that is particularly valuable when there are cells with less than five subjects. This was the case in each of our four clinical cells (mandibular anterior/posterior, maxillary anterior/posterior).

All subjects achieved soft tissue signs of anesthesia (lip numbness or negative response to mucosal sticks). However, 29 subjects reported pain during tooth preparation. Therefore, soft tissue signs were not an accurate indication of clinical anesthesia and produced a false-positive result in 21% (29/138) of our patients.

When analyzed using the Fisher's Exact Test (2-tail), positive postinjection electric pulp test readings (non-80/80) correspond to anesthetic problems (mild or moderate pain) during operative procedures $5.98E^{-10}$ with a P value of < 0.00001 (Table 3). This means that there is a 99% probability that anesthetic difficulties will occur.

DISCUSSION

The results of this study indicate that the Analytical Technology electric pulp tester can be a valuable aid in predicting potential anesthetic problems in operative dentistry. These findings confirm similar results of previous studies (Dreven & others, 1987; Mikesell & others, 1987; Vreeland & others, 1989) that used the electric pulp tester to evaluate clinical anesthesia.

Conversely, the results of this study show the fallibility of using soft tissue signs to predict pulpal anesthesia. All subjects had the subjective soft tissue signs of either lip numbness or a negative response to mucosal stick. However, 29 subjects had pain during tooth preparation. This finding was consistent with investigations evaluating pulpal anesthesia by

using soft tissue signs (McDaniel & others, 1973; Dreven & others, 1987; Mikesell & others, 1987; Vreeland & others, 1989.

This study also demonstrated that the mandibular anterior teeth are predictably the most difficult to anesthetize, with complete local anesthesia being achieved only 22% of the time. These results confirm the findings of Nist and others (1992), who found that the inferior alveolar nerve block achieved complete local anesthesia in the mandibular central incisors 15% of the time and in the mandibular lateral incisors 35% of the time. Vreeland and others (1989) reported the mandibular anterior teeth were more difficult to anesthetize than the posterior. Their study found anesthetic problems in 43-57% of the molars, 43-60% of the canines, and 57-80% of the lateral incisors.

Potential failures were limited by the selection of experimental carious lesions. No lesion was within 1 millimeter of the pulp, and no tooth had signs of periradicular pathology when recent radiographs were examined. Subjects reported no previous pain or sensitivity in the affected teeth. There were also no clinical or radiographic signs of periodontal disease.

Another step taken in the design of the study to eliminate a potential anesthetic problem was to allow appropriate waiting periods after the anesthetic agent had been deposited. Fifteen minutes of onset time was allowed for mandibular anesthesia, as recommended by Vreeland and others (1989). The 5-minute onset time chosen for the maxilla was based on the research of Mikesell and others (1987). The results of this study supports Kaufman's report (1984), which disclosed that maxillary anesthesia is clinically more predictable than mandibular anesthesia. Only three subjects reported pain in maxillary teeth during tooth preparation and it was "mild" (pain rating 1).

In this study 21% of the total procedures induced pain. This number compares with the survey by Kaufman and others (1984) that identified problems in 13% of injections. However, dentists in Kaufman's study may not have identified our pain rating 1 (mild pain) as an anesthetic failure, since no additional anesthesia was required. Our investigation found 10% of subjects reported a pain rating of 2 (moderate pain, requiring additional anesthesia), which coincides with Kaufman's findings.

In five cases subjects reported a "sensation ... but not painful" during the procedure after an 80/80 postinjection reading. When questioned, all subjects rated the sensation as mild (1) or (0) because it was not painless, nor unpleasant, yet no other category existed in our visual analog scale. To be consistent, the researchers reported the data as mild (1) pain, but feel this result to be a false positive, since it does not meet any of the design parameters of our visual analog scale. Significantly, no subject reported the need for additional anesthesia after an 80/80 postanesthesia electric pulp test reading.

Once a potential anesthetic problem is identified with the electric pulp tester, supplemental anesthesia can be reliably administered to avoid patient discomfort during operative therapy. For posterior teeth the periodontal ligament injection has been shown to be an effective supplement to the inferior alveolar nerve block (Walton & Abbott, 1981). The incisive nerve block (injection at the mental foramen) can be used as an adjunct to the inferior alveolar nerve block. Nist and others (1992) found that an incisive/inferior alveolar injection combination produced effective pulpal anesthesia in the first and second premolars and enhanced anesthesia in the lateral incisor and first molar. In the mandibular anterior, labial or lingual infiltration can act to enhance the inferior alveolar block. Clark and others (1991) found that in mandibular lateral incisors, anesthetic success rates increased from 40 to 60% when these supplemental infiltration techniques were used. They found that labial and lingual infiltrations produced similar results when added to an inferior alveolar nerve block. However, they reported the labial injection easier to perform. Therefore, the labial infiltration would be the supplemental injection technique of choice in the mandibular anterior.

CONCLUSIONS

This clinical investigation found the Analytic Technology electric pulp tester to be an accurate predictor of the level of clinical pulpal anesthesia. It demonstrated that soft tissue signs of anesthesia were not reliable indicators of local anesthesia. Also, onset of lip anesthesia as evaluated by subjective questioning and/or mucosal sticks were not a reliable indicator of the onset of pulpal anesthesia.

The results of this study also identify which teeth provide the most anesthetic difficulties. The operative clinician can expect more anesthetic problems in the mandibular than in the maxillary teeth.

The electric pulp tester did accurately predict the level of local anesthesia and therefore alerted the clinician to potential anesthetic problems. It is a valuable clinical aid to practicing dentists, which could enable them to objectively monitor the course of anesthesia prior to the restorative procedure.

This information can be used by the treating clinician to avoid untoward dental pain associated with tooth preparation by using supplemental anesthetic techniques. The following supplemental techniques have been demonstrated to be effective in other clinical studies (Mikesell & others, 1987;

Vreeland & others, 1989; Walton & Abbott, 1981; Nist & others, 1992; Wallace & others, 1985; Clark & others, 1991):

1. Incisive nerve block and periodontal ligament injection in mandibular posterior teeth, and
2. Incisive nerve block and labial infiltration in mandibular anterior teeth.

The ability to accurately predict and then alleviate potential dental pain would greatly relieve both operator and patient anxiety. This ability would significantly enhance patient satisfaction and ultimately increase the quality of dental treatment to our patients.

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Effect of Mode of Conditioning Treatment on Efficacy of Dentin Bonding

S UNO • W J FINGER

Clinical Relevance
Mechanical agitation of conditioning agents during application on dentin and enamel are considered neither necessary nor desirable.

SUMMARY

The effect of the mode of application of the Gluma bonding systems' conditioning agents on dentin bonding efficacy was investigated. The reason for this study was the apparent conflict between the manufacturer's instruction to rub the cavity for 30 seconds with a pellet soaked with the conditioning agent and the poor access to some cavity types, which may make it impossible to do so. The efficacy of dentin bonding with or without rubbing conditioning was not different in terms of shear bond strength and marginal cavity adaptation. SEM analysis of the coupling zone showed different resin-impregnated layer thicknesses resulting from the two modes of conditioning. These differences have, however, no impact on the quality of the bond mediated, provided that, as with the Gluma bonding systems, the primer and/or the adhesive resin have perfectly wetted and penetrated the surface collagen and that the degree of polymerization of the resin in the coupling hybrid layer is adequate. The mode of conditioning, therefore, is not critical for dentin bonding with the Gluma systems.

Hokkaido University, School of Dentistry, Department of Operative Dentistry, Kita 13, Nishi 7, Kita-ku, Sapporo 060, Japan

Shigeru Uno, DDS, DDSc, lecturer

Werner J Finger, DMD, PhD, professor, Dental School of the RWTH, Aachen, Germany, and Bayer Dental, Department of Medicine, Dormagen, Germany

INTRODUCTION

The Gluma dentin bonding systems utilize conditioning procedures to remove the smear layer and demineralize superficially inter- and peritubular dentin prior to priming with a hydrophilic monomer. Such priming is indispensable for formation of resin-impregnated collagen, the so-called "hybrid layer," as a coupling zone between the restorative material and the solid dentin (Nakabayashi, Kojima & Masuhara, 1982). In the original Gluma system a neutralized 0.5 m EDTA solution is applied as an agent for mild demineralization (Munksgaard & Asmussen, 1984), while the Gluma 2000 system uses an acidic aluminum-oxalate solution (de Araujo & Asmussen, 1989) for simultaneous conditioning of enamel and dentin. The manufacturer's instructions for both bonding systems suggest application of the conditioning liquid by rubbing the dentin for 30 seconds with a soaked pellet.

The topography and accessibility of some dental cavities, e g, class 2 or 3 types, however, make it often impossible or difficult to follow this recommendation. Presumably, the reason for this particular handling mode is that agitation of the demineralizing solution will enhance diffusion at the interface and thus the conditioning effect. No information is available on the effect of rubbing or dabbing procedures with soaked

pellets on the resulting quality of the bond. Since separate conditioning of dentin and enamel is not feasible or provided for by the instructions, rubbing or dabbing action will unavoidably interfere with the delicate prismatic enamel pattern. The consequences of such interferences are not known but probably not advantageous.

Therefore, the purpose of the present laboratory study was to investigate the effects of Gluma and Gluma 2000 conditioning agents applied with or without rubbing action on the bonding efficacy to dentin.

METHODS AND MATERIALS

The materials used in this study (manufactured by Bayer Dental, Leverkusen, Germany) are listed in Table 1. The effect of the conditioning modes on dentin was investigated by shear bond strength measurements, by marginal adaptation of bonded composite resin restorations placed in dentin cavities, and finally by SEM evaluation of conditioned dentin and of the coupling zone between filling material and tooth.

For this study a random sample of extracted human premolars and molars, stored in 1% Chloramine T (Struers, Copenhagen, Denmark) for a maximum of 3 months, was used.

For the determination of shear bond strength to dentin, 30 teeth were embedded in epoxy resin. Flat approximal or buccal dentin surfaces were produced by wet grinding on SiC paper (Carbimat, Buehler Ltd, Lake Bluff, IL 60044), from grits of 240 up to 600. The teeth were divided into the following treatment groups of 10 teeth each:

Group I: Conditioning of dentin with the aluminum-oxalate solution G2-1 for 30 seconds followed by 10 seconds' rinsing with deionized water and gentle air drying. Then the surface was kept wet with the adhesive priming resin G2-2 for 30 seconds. The water-ethanol solvent of this compound was carefully evaporated with a gentle blast of compressed air, and finally a thin layer of GL 4, an unfilled resin sealer, was applied, gently air thinned, and light activated for 30 seconds with the curing unit Translux CL (Kulzer GmbH, Friedrichsdorf, Germany). The performance of the curing unit was monitored daily with a radiometer (CL-Tester, Dendema AB, Djursholm, Sweden).

Table 1. Materials Used

Type of Material	Brand	Code	Batch #
Conditioning agent	Gluma 2000-1	G2-1	1397 H
	Gluma 2 cleanser	GL 2	1107 J
Adhesive primer	Gluma 2000-2	G2-2	1442 H
	Gluma 3 primer	GL 3	1036 K
Adhesive resin	Gluma 4 sealer	GL 4	1041 K
Composite resin	Pekafill (U)	PF	1100 X

Group II: Dentin conditioning as in Group I above. Instead of G2-2, the GL 3 primer was applied for 30 seconds. Following drying with compressed air, GL 4 was applied and activated as described above.

Group III: Dentin conditioning with the neutral EDTA solution GL 2 for 30 seconds. Priming and sealing as in Group II.

In each group five teeth were conditioned by rubbing the dentin with a soaked pellet (Procedure A), while the remaining teeth's dentin was kept wet with the conditioning liquid only without rubbing (Procedure B).

As a common procedure for all groups, the light-cured hybrid-type composite resin material Pekafill (PF) was placed in a cylindrical split Teflon mold, 3.5 mm in diameter and 1.0 mm in height, which was clamped on the pretreated dentin site. The restorative material was covered with a transparent matrix strip prior to 60 seconds' light activation with the flat light exit end of the curing unit's handpiece in contact with the strip. Immediately after activation the specimens were immersed in 37 °C warm water for 24 hours prior to shear loading (Universal Testing Machine, Zwick, Ulm, Germany) via a metal rod acting on the composite resin cylinder approximately 0.2 mm apart from and parallel to the bonding interface at a rate of 1 mm/min until rupture occurred. Shear bond strength was calculated as the quotient from fracture load and bonding area.

For the evaluation of marginal adaptation, cylindrical butt-joint cavities, 3 mm wide and approximately 1.5 mm deep with a 90° cavosurface angle, were prepared in a flat peripheral dentin surface, produced by wet grinding on 600-grit SiC paper, with a cylindrical diamond point on a microengine handpiece. For each mode of application of the conditioner and for each of the three treatment groups above, 10 cavities were filled with PF, covered with a matrix strip, and light activated for 60 seconds prior to immersion in deionized water (23 °C) for 15 minutes. Then the filling excess was removed and the cavity margin exposed by gentle wet grinding on SiC paper, grits 600 and finally 4000. The cavity margin was then inspected at X500 magnification (Orthoplan, Leitz, Germany). When a gap was present the maximum width was measured with an ocular screw micrometer at an accuracy of 0.2 µm. The inspection and measurement procedures were completed within less than 3 minutes, in order to prevent dehydration artifacts.

For SEM inspection, flat dentin surfaces, prepared as mentioned above, were treated with the G2-1

Table 2. Shear Bond Strength (in MPa) to Dentin by Treatment Groups and by Modes of Application of Conditioning Liquid (A = with and B = without Rubbing)

	A		B
Group I	18.6 ± 4.6	n s	16.5 ± 1.5
Group II	14.9 ± 1.7	n s	13.2 ± 3.4
	n s		n s
Group III	15.7 ± 1.8	n s	13.7 ± 2.2

n = 5; n s = not significant at $P = 0.05$.

conditioner with or without rubbing of a soaked cotton pellet for 30 seconds, followed by rinsing with water and drying.

For determination of the failure mode by SEM, one random sample from each of the Group I shear bond strength subgroups was selected. The dentin-side parts of the debonded samples were etched by immersion in 10% citric acid for 60 seconds, rinsed, and dried.

A third set of two teeth, one for each conditioning mode from the Group I procedure, was prepared as for shear bond strength testing. The specimens were cut perpendicular through the bonding interface with a diamond saw at low speed. In order to enhance visibility of the resin-impregnated coupling zone, the sections were superficially demineralized with 10% citric acid for 60 seconds and deproteinized with NaOCl solution (Aldrich-Chemie, Steinheim, Germany) for 5 seconds.

All specimens of this investigation were produced at ambient laboratory atmosphere of 23 ± 1 °C and 50 ± 5% relative humidity.

Table 3. Maximum Widths of Marginal Gaps (μm) by Treatment Groups and by Modes of Application of the Conditioning Liquid (A = with and B = without Rubbing)

Group I		Group II		Group III	
A	B	A	B	A	B
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0.4	0.3
0	0.8	0	0.4	0.5	0.6
0.4	1.0	0	0.8	0.5	0.8
0.6	1.4	0.8	0.8	0.5	0.8
0.8	1.5	1.0	1.1	0.5	0.8

No significant differences were found between the six groups when tested by Kruskal-Wallis one-way analysis of variance by ranks ($P > 0.05$).

RESULTS

The average shear bond strengths together with their standard deviations are shown in Table 2. When tested by ANOVA no differences were found between Procedures A and B for each group ($P > 0.05$), while there were significant differences ($P = 0.025$) between the groups. According to a Tukey multiple comparison test, Group I, representing the Gluma 2000 system, showed significantly higher shear bond strength than Groups II and III, which were not different at the 5% level.

The marginal performances of the six conditions studied (Table 3) were compared by the Kruskal-Wallis procedure, which is a nonparametric analysis of variance by ranks. At the 0.05 level of significance no differences were found. Five to eight cavities within each group of 10 specimens were free of gaps. The maximum width of a gap found was 1.5 μm.

A morphological analysis of differences between the two modes of application of the conditioning liquid was made for the Group I procedure only. Figure 1 shows that the smear layer is completely removed from dentin. The entrances of the tubules are opened, and the grooves from grinding on SiC paper are still visible. The intertubular dentin looks smooth and uniform. The only morphological difference between the procedures is that with Procedure B some tubules are still partly occluded in contrast to the sample representing Procedure A.

Figure 2 compares the failure patterns of specimens produced by the two conditioning modes. Both SEMs show resin tags filling the tubules and broken at their bases. The citric acid etching has not disclosed the characteristic appearance of etched dentin. Therefore the fracture is considered cohesive in resin or in the hybrid layer. The shear bond strengths of the two specimens were 14.3 and 14.1 MPa respectively. No morphological differences were found. In Figure 3 the lower parts of the SEM photographs show resin and the upper halves dentin on sections cut perpendicular through the bonding surface. These distinct areas are divided by a uniformly wide zone, which is clearly different in morphology from the substrates above and underneath. This zone is approximately 4.0 μm wide for Procedure A, and 3.0 μm for Procedure B. Resin tags extending into dentin are seen in both SEMs. These tags are wider at the bases than in deeper dentin.

DISCUSSION

This study shows that the method of dentin

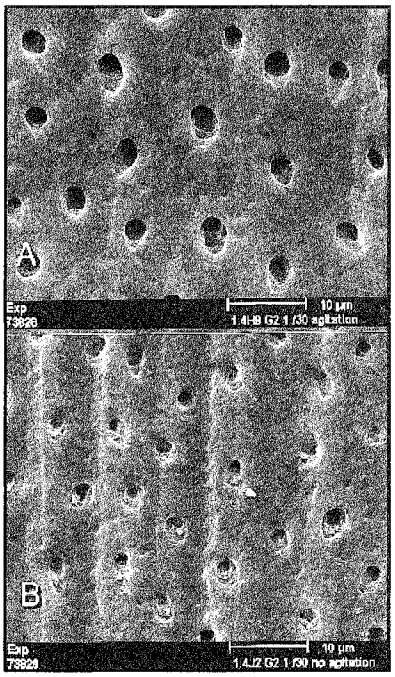

Figure 1. *SEM photographs of ground dentin conditioned with G2-1 for 30 seconds with (A) and without (B) rubbing the surface with a soaked pellet*

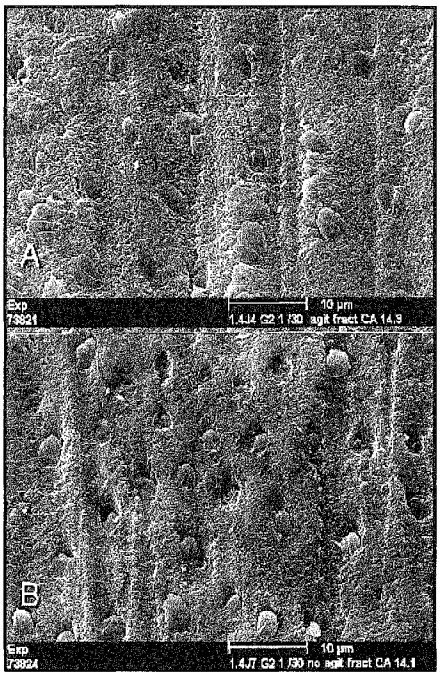

Figure 2. *SEM photographs of fracture patterns after shear debonding of resin cylinders bonded to dentin with Gluma 2000. The specimens were conditioned with (A) or without (B) agitation of the conditioning agent G2-1. Both samples show cohesive failure in resin.*

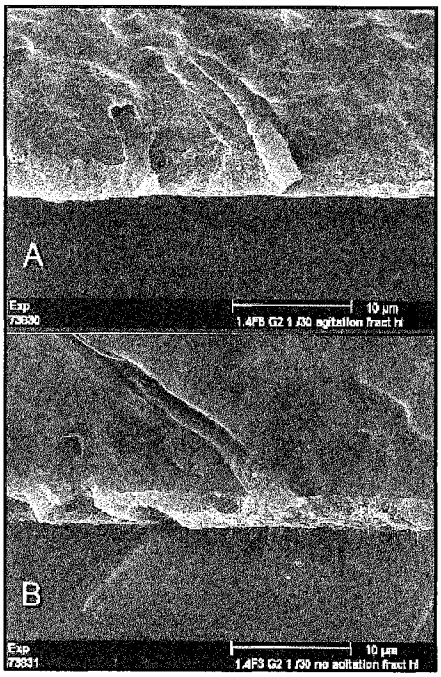

Figure 3. *SEM photographs of sections cut perpendicularly through the coupling interface of resin specimens bonded to dentin by Gluma 2000. The conditioning liquid G2-1 was applied with (A) or without (B) rubbing action with a soaked pellet for 30 seconds. Upper halves are dentin, lower halves are composites.*

conditioning, either rubbing with a soaked pellet or wetting with the conditioning liquid only, has no influence on the quality of the bond, with Gluma or with Gluma 2000 or with the combination of both systems studied in Group II. When tested by bond strength as the target parameter, Group I showed significantly higher shear bond strengths than Groups II and III. Differences in wetting and penetration of the priming adhesive resins G2-2 and GL 3 in dentin conditioned with G2-1 and GL 2 cannot explain these differences (Finger, Inoue & Asmussen, 1994). It is therefore hypothesized that differences in shear bond strength result from differences in primer composition. GL 3 contains HEMA, which is a bifunctional monomer with one methacrylate group only, while G2-2 contains BIS-GMA, a monomer with two methacrylate groups. The latter monomer is thus a crosslinking agent that produces higher polymer network rigidity and thus increased mechanical resistance of the collagen-polymer hybrid layer. Bonding efficacy is unanimously considered a function of the degree of polymerization of the adhesive monomer in the collagen layer exposed by demineralization, even when the layers are extremely thin as, for example, after neutral EDTA conditioning (Erickson, 1989; van Meerbeek & others, 1992; Jacobsen & Finger, 1993). It has to be mentioned that in this study, contrary to the manufacturers' instructions, the GL 4 resin was separately light activated for enhanced bonding efficacy (Crim, 1990; Yanagawa & Finger, 1994; Yamamoto & Finger, 1994). As pointed out by Krejci, Kuster, and Lutz (1993) and by Kubo and others (1992), separate light activation of G2-2 has no effect on bonding efficacy, since the monomer layer left after evaporation of the solvent is extremely thin and thus not polymerizable, due to inhibition by oxygen from the surrounding atmosphere.

Marginal performance is another parameter for the assessment of a restorative bonding system.This method of cavity evaluation reflects practical performance of bonding systems more closely and should therefore be considered together with bond strength data (Finger & Ohsawa, 1987; Prati & others, 1990). The results of this cavity test showed no differences either between the materials or between the conditioning procedures.

The morphology of the dentin was not affected by the mode of conditioning. The same is true for the failure patterns, which were consistently cohesive in resin, as also previously reported by Finger and others (1994). The debonding sites were located

either inside the hybrid layer or at the interface between the hybrid zone and the restorative resin, which is in agreement with the failure patterns previously described for the Gluma 2000 system by Malferrari, Finger, and García-Godoy (1995).

The only obvious difference related to the mode of conditioning found in this study was the thickness of the resin-impregnated hybrid layer. Based on the present initial observation, it is assumed that mechanical agitation of the conditioning liquid (e g, rubbing with a soaked pellet) enhances the depth of demineralization, due to increased diffusion and dissolution activity at the surface. This will result in a thicker hybrid layer. The effect is directly comparable to the effects of different conditioning times, which also result in hybrid layers of different thickness. In spite of such morphological differences, the bond strengths found were not significantly different, which is in agreement with a previously published report (Malferrari & others, 1995).The reason is that debonding apparently occurs within the hybrid layer. The strength of this zone is probably a function of the completeness of adhesive resin penetration into the collagen network and of the degree of polymerization.

CONCLUSIONS

It is concluded from this study that with the conditioning time of 30 seconds, as recommended by the manufacturer, the mode of application of the conditioning solution on dentin has no influence on the resulting quality of the bond mediated with either of the Gluma systems. The effect on the retentive enamel pattern of mechanically rubbing enamel during conditioning with a soaked pellet was not investigated in this study. However, based on the findings of Inoue, Finger, and Mueller (1993), even 5 or 15 seconds' etch duration with Gluma 2000-1 produces an enamel pattern, which offers the same resin retention as 30 seconds' etch duration. Thus, it may be anticipated that omission of agitation results in a less deep but still highly effective retentive pattern. Mechanical agitation of conditioning agents during application on dentin and enamel are considered neither necessary nor desirable.

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CLINICAL ARTICLE

E-Z Gold: The New Goldent

K S ALPERSTEIN • L YEARWOOD • D BOSTON

SUMMARY

E-Z Gold is a new direct filling gold material that is similar to existing powdered gold formulations but more user-friendly. It is a mixture of pure gold powder and wax (less than 0.01% organic wax), wrapped in gold foil introduced to the dental profession in the late 1980s, and similar metallurgically to gold foil and powdered gold (Goldent) in that, when properly and thoroughly compacted, it has comparable properties: inertness (biocompatibility) and permanence. E-Z Gold's manipulative characteristics are similar to that of a very stiff amalgam, yet more sticky (cohesive) than gold foil, hence the name E-Z Gold.

There is no reported research related to physical properties regarding shear, tensile, and cohesive strength. One can assume that E-Z Gold is similar to old Goldent but with improved softness and working characteristics. Clinical experience in the use of this new restorative direct filling gold material has been encouraging. We anticipate that in the near future, clinical and laboratory research comparing this gold to other types of direct filling golds will be forthcoming.

Temple University School of Dentistry, Department of Operative Dentistry, 3223 N Broadway St, Philadelphia, PA 19140

Klara S Alperstein, DDS, associate professor

Lionel Yearwood, DDS, assistant professor

Daniel Boston, DMD, associate professor

INTRODUCTION

Teeth restored with direct filling gold materials offer the most permanent type of restorative modality in dentistry. This degree of permanency is not obtained with other materials. It has a coefficient of thermal expansion similar to dentin (O'Brien, 1989). Generally, direct restorative golds offer superior marginal integrity (Hormati & Chan, 1980; Martin, 1981). The density and hardness of compacted gold enables the restoration to withstand the compressive forces of occlusion adequately. No cementing medium is required, and the surface of condensed gold can be efficiently polished, maintaining the luster and smoothness indefinitely. This creates conditions for optimal gingival response, especially in class 5 restorations, thereby preserving a healthy periodontium.

To obtain optimum physical properties, the direct gold materials are placed into the prepared cavity and are strain hardened by condensers under heavy force. Force is required to weld the gold and to minimize porosities. The gold adapts to tooth structure as it is compacted. During condensation, the strength changes from that of pure gold (BHN 25) to that similar to Type I inlay gold (BHN 75) (Baum, Lund & Phillips, 1985). Tensile strength rises from 19,000 psi to 32,000 psi, while yield strength increases to 30,000 psi. The exact mechanisms are not completely understood (Baum & others, 1985).

Disadvantages include potential fracture of condensed gold under severe shear stresses where stress is not absorbed by surrounding tooth structure.

Ideal density of the restoration should measure 19.3 grams per cubic centimeter; however, this is not

achieved in practice. The best achievable density is that of approximately 18.0 grams per cubic centimeter. This difference is due to the presence of porosity and voids (Baum & others, 1985). A comparison of the density with those of silver/mercury alloys indicates that direct gold is inferior. Therefore, since direct gold is not strong enough to resist deformation, it should not be used as a crown or to restore lesions subject to heavy occlusal forces (Baum & others, 1985).

In addition to the inability to achieve maximum density, there are only three minor disadvantages: color, thermal conductivity, and difficulty in manipulation (Coy, 1957). Color can be addressed as an issue of individual or cultural preference. Thermal conductivity has been studied by many in terms of pulpal response. In the study by Thomas, Stanley, and Gilmore (1969), the accepted gold foil procedure was used to reproduce the conditions of clinical practice. Results showed that the condensation of gold foil into sound teeth produced moderate responses initially, with resolution occurring after somewhat longer time intervals. The use of a cement base reduced the response, and those teeth which preoperatively formed irregular dentin showed no adverse response. These findings indicate that the gold foil restoration is biologically sound (Thomas & others, 1969). Another clinical evaluation concluded that it was difficult to isolate malleting as the only factor responsible for the few pulpal problems that occurred without taking into account factors such as damage from cavity preparation, depth of the restoration, irritating bases, or heat from polishing (Balaban & others, 1986).

With its ease of manipulation, E-Z Gold (Ivoclar North America, Amherst, NY 14228) could offer encouragement to those who would like to introduce direct gold into their practice for the first time or reintroduce it to those who gave it up as a result of past experiences. This paper does not intend to present scientific evidence of the superiority or inferiority of this new product. The intent is to inform the reader of the availability of E-Z Gold in an attempt to rekindle use of direct gold in indicated clinical cases and to stimulate research related to its use.

CLASSIFICATION OF DIRECT FILLING GOLD

There are two main categories of direct gold materials: precipitated gold and gold foil (Marzouk, 1985). Precipitated golds are formed by chemical or electrical precipitation to form crystals of pure gold, or by a process of atomization, which produces spherical gold particles. These materials are supplied as powdered gold (e g, Goldent), mat gold, and Electraloy RV (Ivoclar), which is an alloy of gold and calcium (0.1%). Goldent was introduced in the United States in the early 1960s (originally by Morgan, Hastings Co, now by Ivoclar). In 1989 a new granular type of direct gold, Stopfgold (Degussa Corp, Plainfield, NJ 07080), was introduced (Dhiek & Rigelstein, 1989) that morphologically differs from previously available direct filling golds (Elderton & Boyde, 1971). It is similar to Electraloy RV in its properties and handling characteristics (Lambert, 1994) except that it offers an increase in shear strength of 50% when compared to gold foil. The oldest and most durable direct gold is gold foil, which is supplied in four forms: plain foil, corrugated foil, platinum foil, and laminated foil (Marzouk, 1985).

All of the forms of gold listed may be either cohesive or noncohesive. They are noncohesive if surface impurities are present that prevent one increment of gold from cohering to another. The manufacturer supplies books of gold foil in cohesive and noncohesive states. Strips of mat gold, mat foil, and Electraloy RV are essentially cohesive when purchased, but may become contaminated with some impurities during shipment. Because gold attracts gases that render it noncohesive, these gases must be removed from the surface of gold before cold welding. To ensure cohesion, direct filling golds are degassed or decontaminated (Marzouk, 1985) using heat. All direct filling gold products are degassed immediately prior to use except when noncohesive foil is specifically desired (Sturvedant, 1985).

This process of degassing is different for powdered gold (Goldent) and for gold foil. Goldent and E-Z Gold are supplied with a wax coating that must be burned off before compaction. The principles of placing the restoration and the mechanism for cohesion and finishing have not changed with the new developments (Gilmore & Lund, 1973).

INDICATIONS

Because of the nature of cohesive gold, it is advisable not to expose the restoration to excessive stresses such as the shear forces that occur during mastication.

Direct gold should not be used to restore teeth with large pulp chambers and moderate to severe periodontal involvement (Sturdevant, 1985). The smaller the lesion, the more suitable it is for direct gold. E-Z Gold (Figure 1) is recommended for use in small class 1 and class 5 lesions. Patient preference for gold restorations (Figures 2A-2C) will influence the treatment plan for direct gold.

The cast restoration is generally considered to be a stable and reliable option in restorative dentistry; however, it may become defective if caries develops at a margin or if the occlusal surface is perforated

Figure 1. *E-Z Gold*

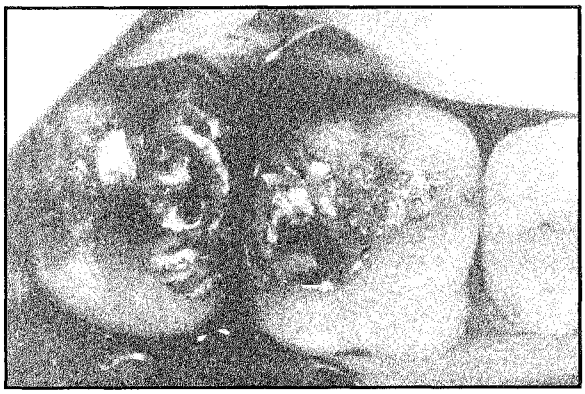

Figure 2B. *Restored tooth prior to finishing*

due to an endodontic access or occlusal wear. When the defect is not extensive, consideration should be given to repair with E-Z Gold (Figures 3A-3C) rather than replacement of the casting. This is particularly true if the restoration is an abutment for an existing fixed or removable prosthesis.

Three factors having the greatest influence on the success of a casting repair are: access to area, ability to obtain adequate isolation, and a choice of restorative material. Research on the interface leakage of direct restorative materials has generally indicated that direct gold restorations offer superior margin adaptation when properly manipulated

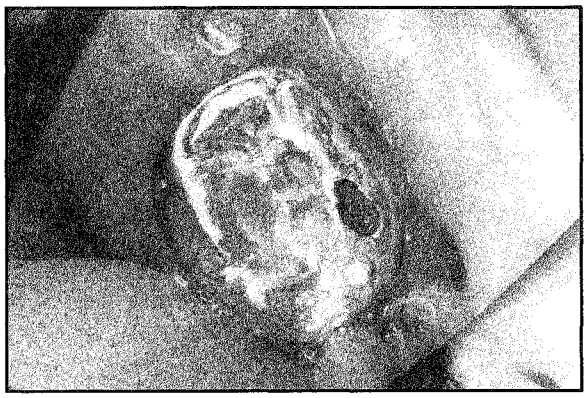

Figure 3A. *Perforation of existing full cast restoration*

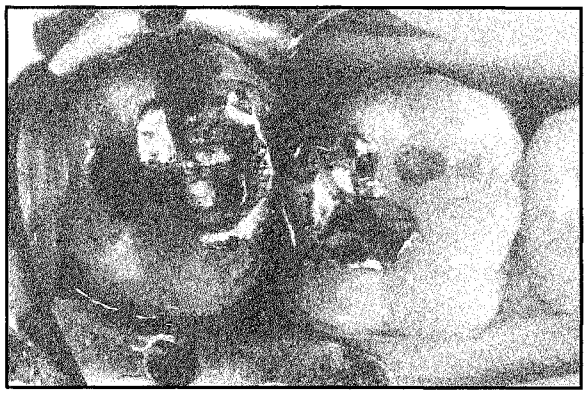

Figure 2A. *Existing multiple cast restorations with new adjacent occlusal carious lesions*

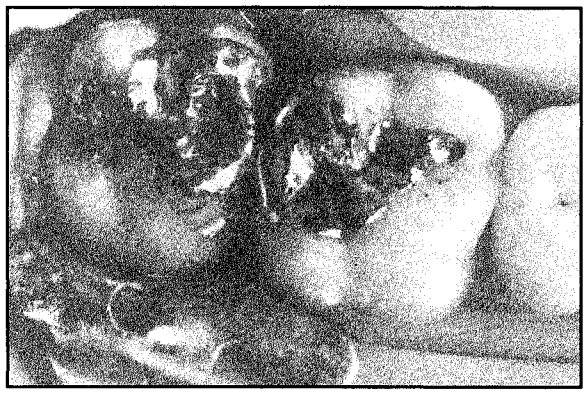

Figure 2C. *Finished occlusal restorations*

(Hormati & Chan, 1980). Amalgam is recommended as a second choice (Fitch & others, 1982). Composites are contraindicated because of poor sealing ability (lack of bond between metal and composite) and questionable compatibility with gold alloys.

Clinical Experience

Cavity preparation when using E-Z Gold is similar to one for amalgam (Marzouk, 1985). Condensation,

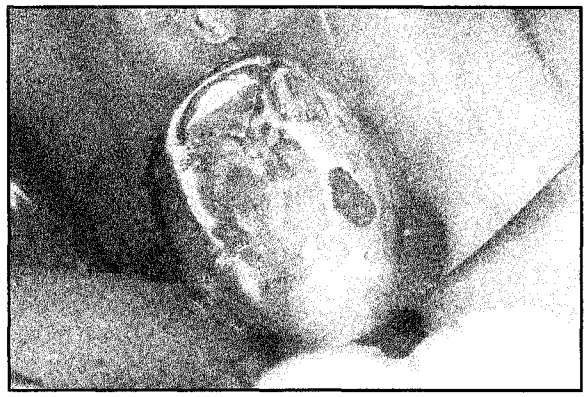

Figure 3B. *Cavity preparation of defective area*

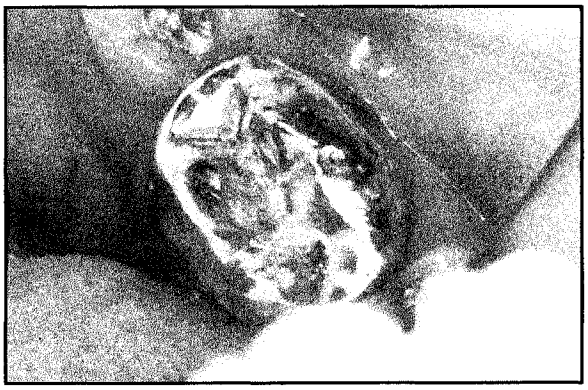

Figure 3C. *Completed restoration*

finishing, and polishing are similar to handling of the old Goldent.

Cavity Preparation

Placement of the rubber dam and complete moisture control is essential (Ingraham & others, 1980).

1. A box-like preparation is required (with sides, ends, and a floor), because E-Z Gold has a tendency to fragment and spread out when initial pressure is applied. Sharp internal line angles are not necessary.
2. Precisely cut line and point angles are not necessary; round internal retention is acceptable, rounded retentive grooves (use #1/2 or #1 round burs sizes) being adequate to retain gold.
3. Margins should be butt joints, although a slight bevel is permissible but without flares (Baum & others, 1985).

Heating Phase

1. Spear a pellet with an annealing instrument (#4) and hold it 1/2"-1" above the flame (Figure 4).
2. The pellet will catch fire, as the waxy matrix burns away. Do not move the pellet away from the flame while the wax is burning.
3. After the wax substrate has burned off, keep the pellet in the flame for 2-3 more seconds until it glows with a dull red color.
4. Remove from flame. Wait a moment for the pellet to cool, then place it in the cavity.

The pellet will tend to "sputter" while it's burning.

Avoid too much heat (white-hot color), as this will melt the gold powder. The pellet will shrink and become very hard and unmanageable.

An underheated pellet will have a waxy consistency because of the remaining organic matrix.

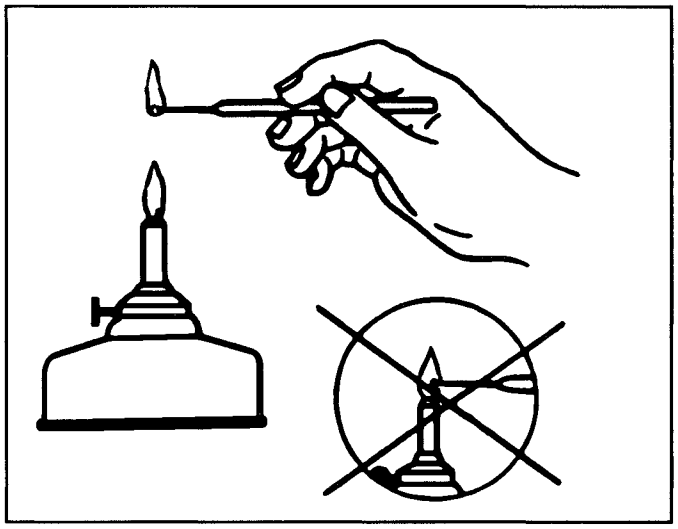

Figure 4. *Annealing E-Z Gold*

Condensation Phase

1. Transfer the annealed pellet to the cavity preparation. An amalgam condenser is used to press the pellet into the bottom half of the cavity preparation (Figure 5). If the cavity is larger than the available pellets, two or three pellets are placed simultaneously. Do not condense until the pellet(s) has been tamped into position.
2. Using the small condenser (hand instruments: E-Z Gold condensers #1 and #2, Thompson Dental Mfg, Missoula, MT 59801 or serrated amalgam condenser), condense pellets into retentive areas. The condenser is stepped over the entire mass of gold so that each condensed site overlaps the previously condensed site (Figure 5). If the gold tends to rock within the cavity, the initial pellet was too small. Try again with a larger pellet. When at least half of the preparation has been filled with the material, the remainder of the gold can then be condensed either with hand instruments or an Electromallet (McShirley Products, Inc, Valencia, CA 91355) set at a low frequency and moderate intensity.
3. Continue the build-up by adding one pellet at

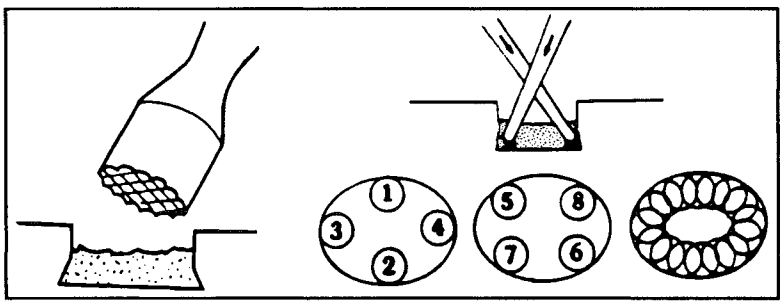

Figure 5. *E-Z Gold condensation (steps 1 - 4)*

a time; condense each thoroughly before adding the next one. Successive pellets are placed and condensed so that the walls are banked and the restoration is concave.

Before adding additional pellets, probe the surface vigorously with a stiff explorer to be sure all the air (porosity) has been eliminated and that adequate retention has been achieved. If the explorer sinks or penetrates into the gold, use the condenser again with more force and pressure. If it does not leave a hole, the gold is well condensed. Continue until the cavity is slightly overfilled to allow for proper finish. The final surface is condensed with a foot condenser using high frequency and moderate intensity to create a dense, even surface.

Finishing and Polishing

1. Burnish the restoration using a #4 nondirectional E-Z Gold file (Thompson Dental Mfg) or an amalgam burnisher.
2. Apply a revolving white stone or finishing bur to finish the surface as one would an amalgam.
3. After removing excess, establish proper contour.
4. Burnish the surface with a discoid or ball burnisher to strain harden the surface.
5. Final polish is accomplished with Sof-Lex disks (3M Dental Products, St Paul, MN 55144), pumice, and amalgloss.

Final polish is often optional.

DISCUSSION

With advancement of technology and introduction of new materials to the practice of dentistry, general dentists should incorporate improved restorative services for their patients. Although some patients may not accept the proposed treatment, it is the dentist's responsibility to recommend the best possible treatment based upon the needs of the tooth and permanency and longevity of the restoration recommended (Mjör & Medina, 1993).

As we move into the twenty-first century, with an increase in life expectancy, there will be an increase in the senior citizen population. It is expected that these patients will demand and expect a high level of dental services along with a higher level of quality of life (Medina, 1987). Direct filling gold restorations have proven over time to offer superior quality in terms of permanency and biocompatibility. With E-Z Gold available, the dental practitioner can deliver an excellent restoration with relative ease and possibly at a lower cost. General armamentarium available in the dental office can be utilized in tooth preparation, material condensation, finishing, and polishing of E-Z Gold. This is encouraging, since with continued de-emphasis on teaching of direct filling gold in dental schools (Lambert, 1980, 1990; Nuckles, 1989), it's becoming more difficult to purchase mechanical condensers (McShirley Electromallet) and other gold foil instruments.

CONCLUSION

Although direct filling gold is no longer the dentist's first choice for most restorations, it still has a place in today's ever-growing selection of restorative materials. Knowing how and when to use direct filling golds can be an invaluable service to patients and subsequently a significant practice builder. With the development of E-Z Gold by Lloyd Baum in the late 1980s, direct filling gold restorations have become easier to place.

This improved manageability has made the restoration placement less time-consuming and more predictable. Its use, however, should be limited to small lesions for optimum success. Clinical experience, as with other forms of gold, will dictate use in larger lesions.

By incorporating direct filling gold into a practice, dentists can offer their patients a restoration with greater expected longevity and better tissue response than either amalgam or composite and provide optimum restorative care.

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Clinician of the Year Award

Over the past decade I have had the pleasure of knowing Dr Richard Hoard as a close friend and outstanding clinician in the academy. Richard has given a lot to his profession and to this academy. Since his beginnings at Humbolt State University, he has dedicated his career to the science, practice, and teaching of operative dentistry. Dr Robert Wolcott recognized the potential of this young man shortly after his graduation from Loyola School of Dentistry and placed him on the operative faculty at UCLA. Once there, he rapidly progressed from assistant professor to associate clinical professor, acting chairman, and since 1987 as chairman of the Section of Operative Dentistry.

Dr Hoard remains active in research and has published and lectured extensively on subjects relevant to clinical operative dentistry. He maintains membership in the Dental Materials Group of the American and International Association of Dental Research and has presented several papers to this group. His clinical expertise can be attested to by his long involvement with this academy and many study clubs. He has served as president of the American Academy of Gold Foil Operators, operated at several of its annual meetings, and has presented lectures at AAGFO meetings both in the United States and abroad. He has been instrumental in the founding and mentoring of the UCLA Restorative Study Club, teaching both direct and cast gold techniques.

The best testimonial to Dr Hoard probably comes from his students. He has been recognized as Outstanding Operative Instructor at UCLA by graduating classes for four years in a row. In addition, he received the Special Award for Outstanding Service from the class of 1981, the Best Clinical Instructor award from the class of 1983, and the Faculty Award for Outstanding Service and Advancement of Education Ideals from the class of 1994.

Richard J Hoard

We have all come to know Rick as a warm, energetic, and fun-loving friend, and it is with our heartfelt appreciation for his service and leadership to this academy and the profession that we present him with the Clinician of the Year Award for 1995.

FREDERICK C EICHMILLER

©OPERATIVE DENTISTRY, 1996, 21, 43

Distinguished Member Award

The recipient of the Distinguished Member Award this year is none other than our good friend and colleague, Ralph J Werner.

For someone to receive a Distinguished Member Award there must be some feature about this individual that distinguishes him above his fellows. For Ralph, this unique feature is his tremendous silent impact on the dental profession.

For some reason or other he just seems to be the power behind the throne in about everything in which he gets involved. According to my list, Ralph participates in 18 different national dental organizations; one, of course, is our American Academy of Gold Foil Operators, of which he was president some 25 years ago. Every organization into which he enters soon discovers his unique managerial skills and administrative ability at keeping the train on track and going full speed ahead without going bankrupt in the process. Much of the time he is found serving as secretary, where he can, with a low profile, influence operational affairs of the organization.

A classic example is the Academy of Operative Dentistry. From 1972 until the present, we have seen this small group evolve into probably the largest enthusiastic organization of dentists (over 1000 active members) in our nation today. Ralph, as its spark plug, has developed this group of dentists into an organization that, along with our American Academy of Gold Foil Operators, is giving status and recognition to operative dentistry today.

In 1990 Ralph received the Operative Dentistry Award of Excellence from our friend and colleague, Anthony D Romano, which was reported on pages 110 and 111 of *Operative Dentistry* of that year. The reader is referred to the journal of that year (volume 15) for a more complete listing of his accomplishments.

Despite all of these accolades, Ralph is one of those rare individuals who prefers internal satisfaction for the things he has accomplished rather than praise from his contemporaries. He is most content when the acts speak for themselves.

Ralph was born on 26 September 1922 in Bloomer, Wisconsin. Grade school and high school were spent in Bloomer, where the population was only 3000. He traveled 100 miles to attend dental school at the University of Minnesota, where he graduated in 1945 at the age of 22. He then established a dental office in Menomonie, where he practiced for over 40 years. In the meantime he did a tour of duty for two years in the U S Naval Dental Corps, and took a specialty training course in orthodontics. He also associated for a time with the G V Black Study Club, where he developed a love and sense of respect for operative dentistry and gold foil.

Ralph J Werner

Throughout his entire career, during which he was heavily involved with teaching and instructional activities, Ralph was always the clinician and was always treating patients as a general practitioner, not as a specialist. He is the kind of person you would seek out for consultation in solving a complex clinical problem.

Ralph is a very committed, hard working, happy person. It is my privilege to present this unusual and remarkable man to the American Academy of Gold Foil Operators as the recipient of the 1995 Distinguished Member Award.

LLOYD BAUM

DEPARTMENTS

BOOK REVIEW

DENTAL IMPLANTS: A GUIDE FOR THE GENERAL PRACTITIONER

Michael Norton

Published by Quintessence Publishing Co, London, UK, 1995. 148 pages, 136 illustrations. $68.00.

Dr Norton is a British-trained oral and maxillofacial surgeon, with a one-year internship in dental implants at the Royal London Hospital. His practice concentration is in implants, and he has served as clinical adviser to Astra Tech Implants. The author's purpose in this book is to provide a general introduction to the treatment-planning, surgical, and prosthetic phases in implant restoration.

The hallmark of Quintessence publications is that they have nice color photographs and illustrations, and this book is no exception. It is generally well written, understandable, and easy to read, the British style and terminology notwithstanding. The book is an excellent overview of surgical technique and restorative options, but, although general concepts are outlined, the details are sparse where at times one would have wished for more. At times more pictures of different views may have helped illustrate his descriptions, especially for a novice reader. The author does point out that the emphasis and examples shown are of the Astra Implant System. Zarb, Albrektsson, Lekholm, and Brånemark are often referenced. The book is limited to root-form osseointegrated implants and does not discuss blade, vent, subperiosteal, or transmandibular implant systems. It is by no means comprehensive, as the author presents a single method in detail, with other alternatives and options briefly mentioned, as befits this slim volume. Some concepts and procedures are mentioned without elaboration but always well referenced.

The book is divided into treatment planning, phase I surgery, phase II surgery, single tooth restoration, fixed bridges, precision attachments, overdentures, and maintenance. The section on treatment planning and radiographic evaluation is clear, concise, and well done. The histological and biomaterials aspects of implants and osseointegration are scantily discussed. The author does acknowledge that there is a great variety of implant systems available and describes general surgical principles, using the Astra system as an example. Basic guidelines for implant restoration are presented, and certainly a wide range of options are described. But the author does emphasize that though the basic protocol is similar among various sytems, it is beyond the scope of the book to provide details of individual protocols. He uses the specific example of the Astra system to illustrate his points. Issues that are debatable or controversial are raised, but the author recommends the mainstream consensus opinion and does not seek to analyze or resolve them. Dr Norton is forthright about his relationship to Astra and provides an honest description and appropriately does not become a mere advocate for that system.

The text is of greatest value to the novice to provide a quick overview and introduction to implant-supported restorations. The experienced clinician or specialist, for whom this text was not intended, will find it wanting. The author does not review the current research or cover issues of complications, retreatment, gingival contouring, grafting, augmentation, or preprosthetic surgery, which would be beyond his stated purpose. You get the feeling that there was more to be said, but he is constrained by the scope and size of the book.

There is no doubt that dental implants are a maturing modality that is fast becoming part of a practitioner's restorative options. I would recommend this text as a useful, readable introduction to this topic.

TAR-CHEE AW, DDS, MS
University of Washington
Department of Restorative Dentistry
Box 357456
Seattle, WA 98195-7456

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