CDA

Adjunctive Procedures

Glass Ionomers

C.E. Listings

JOURNAL OF THE CALIFORNIA DENTAL ASSOCIATION VOL.31 NO.6

June 2003

RESTORATIVE ADHESIVES

Restorative-tooth interface strategies for enhancing predictability and longevity

Edmond R. Hewlett, DDS

OF THE CALIFORNIA DENTAL ASSOCIATION

Journal

CDA Journal
Volume 31, Number 6
JUNE 2003

DEPARTMENTS

FEATURES

Revisiting Our History

Jack F. Conley, DDS

There was a time when the history of the dental profession was front and center. Sadly, in a world in which the technology and practice of dentistry have been advancing forward at a rapid speed, particularly in the past decade, it seems that our history has become less visible, and seemingly less important, to many in the profession.

However, revisiting some of the history of the dental profession can show us just how remarkable dentistry's development has been. A review of the accomplishments of our predecessors reminds us of how they shared their findings and techniques with their colleagues. In a fast-paced world of progress, sharing too often comes with a price tag affixed or comes as a result of commercial or corporate support.

A review of our history provides a unique snapshot of the advances in dental practice that we can offer our patients today when compared to the state of the art of 10, 20, 30, or more years ago. Or, if we go back to 1840, when the first dental school was founded in Baltimore and the organized profession was emerging in this country, one would probably find little to compare with the comfort, safety, and technology that is possible in contemporary dentistry.

This becomes important to our task of educating the public about the quality of oral health care we can offer to them. Despite the contributions and sacrifices of our predecessors that have advanced the art and science of dentistry up to and including the present day, dentistry has not always enjoyed a reputation as a pleasant oral health experience. Like it or not, some of our patients still would much prefer spending time and resources on almost any other need (or want) than their oral health.

Our ability to educate our patients and the public with an emphasis on the value, comfort, and safety of contemporary dentistry can be enhanced if we occasionally rely upon history to emphasize the advancements the profession now can offer. We speak not only about capabilities in technology. The Code of Ethics, which is the conscience of the profession, and the numerous contributions of many dentists during the past 150 years to preventive and charitable programs such as fluoridation and Give Kids a Smile, to name just a few, are all part of the heritage that has made it possible for dentistry to develop a respected position in society. We need to remind ourselves of this heritage from time to time.

For all of these reasons, we believe that it is important to revisit our past occasionally. That can be accomplished by perusing the work of gifted writers and historians such as dental colleagues Clifton Dummett and Malvin Ring. However, there is another method open to those who wish to refresh their knowledge of their profession. While we had been aware of its existence for some time, only recently did we discover firsthand the Dr. Samuel D. Harris National Museum of Dentistry. Located in Baltimore at the site of the first college of dentistry in the United States, this museum is a treasure trove of the past with historic artifacts and historical notes that should have appeal and importance to dental colleagues. It is also a magnificent educational resource on oral health for the public with some exhibits geared particularly to children. The museum is probably on a regular visitation schedule for tours of school groups in the area. The current generation of children in Baltimore and adjacent areas are extremely fortunate to have this opportunity to benefit from a close-up education in good oral health.

The museum is a first-class presentation that opened in 1996 with funding from Dr. Samuel Harris, the American Dental Association Foundation, and individuals, groups, and organizations within the organized profession and dental industry. It is an affiliate of the Smithsonian Institution. Dr. Harris, a pioneer in the development of pediatric dental organizations, was a generous philanthropist who passed away earlier this year just a few weeks short of his 100th birthday.

Based upon impressions from our recent visit, while the museum provides obvious value to the public, and particularly to the children that make up our future generations, we believe that it is a must-see for practicing professionals. As we know, it is important that dentists become familiar with the educational information about dentistry and oral health to which the general public is exposed through communication in the media. Similarly, it is essential that the dental community become aware of and conversant with the educational information available in this superb venue. But most importantly, we can renew our respect for the efforts of our professional predecessors who did so much to develop the profession to which we belong.

The National Museum of Dentistry provides a unique opportunity to revisit our history. A visit can also rekindle our pride in the accomplishments of those who have contributed to our stature as a profession while providing an opportunity to experience some first-class oral health educational exhibits. We should express our gratitude to Dr. Harris and the other dental colleagues and friends who supported and helped develop this remarkable tribute to the profession, an achievement in which we all can take immense pride.

Primary Teeth Found a Source of Stem Cells

Scientists report for the first time that primary teeth contain a rich supply of stem cells in their dental pulp. Researchers say this unexpected discovery could have important implications because the stem cells remain alive inside the tooth for a short time after it falls out of a child's mouth, suggesting that the cells could be readily harvested for research.

According to the scientists, who published their findings online in the Proceedings of the National Academy of Sciences, the stem cells are unique compared to many "adult" stem cells in the body. They are long-lived, grow rapidly in culture, and, with careful prompting in the laboratory, have the potential to induce the formation of specialized dentin, bone, and neuronal cells. If follow-up studies extend these initial findings, the scientists speculate they may have identified an important and easily accessible source of stem cells that possibly could be manipulated to repair damaged teeth, induce the regeneration of bone, and treat neural injury or disease.

"Doctors have successfully harvested stem cells from umbilical cord blood for years," said Songtao Shi, DDS, PhD, a scientist at the National Institute of Dental and Craniofacial Research and the senior author on the paper. "Our finding is similar in some ways, in that the stem cells in the tooth are likely latent remnants of an early developmental process."

Shi and colleagues named the cells SHED, which stands for stem cells from human exfoliated deciduous teeth. Shi said the acronym was needed to differentiate SHED from stem cells in adult tissues, such as bone or brain. "Stem cell research has exploded during the past seven or eight years, yet people still talk in general terms of postnatal and adult stem cells as though they are one and the same. Postnatal cells from children may act totally differently than adult stem cells, and we felt the inherent difference needed to be emphasized," Shi said.

The new finding stems from a chance interaction. As Shi recounts, it happened one evening when his then 6-year-old daughter, Julia, asked for help in pulling out a loose primary tooth. "Once it was out, we sat and looked carefully at the tooth," recalled Shi, a pediatric dentist. "I said, 'Wait a minute, there is some red-colored tissue inside of the tooth,' so I took the tooth to my laboratory the next day and examined it. Sure enough, it had beautiful pulp tissue left over."

A few days later, when another of Julia's teeth came out, Shi said he was better prepared. He placed the tooth into a liquid medium used to culture cells, drove it to the laboratory, and extracted the dental pulp. Soon thereafter, he succeeded in isolating living stem cells from the tissue, a discovery that would lead to the collection of more exfoliated teeth from Julia and other children.

The group launched an initial round of studies to determine whether the cells would grow well in culture. Using dental pulp extracted from the children's exfoliated incisors, they discovered that about 12 to 20 stem cells from each tooth reproducibly had the ability to colonize and grow in culture.

"We also found the SHED behaved much differently than dental pulp stem cells from permanent teeth, which our group studied previously," said Masako Miura, MD, PhD, an NIDCR scientist and a lead author on the study. "They exhibited an ability to grow much faster and doubled their populations in culture at a greater rate, suggesting SHED may be in a more immature state than adult stem cells."

Muria said she and her colleagues soon found these cells could be prompted to express proteins on their surface indicative of stem cells that were in the process of switching into bone and dental pulp cells. This discovery led to additional follow-up experiments, led by Bai Lu, PhD, of the National Institute of Child Health and Human Development, to determine whether SHED also possessed the potential to switch into neural and fat cells. The groups found, under specific cell culture conditions, that the cells responded accordingly, expressing a variety of proteins indicative of neural and fat cells.

"These data are just the start," Shi said. "We're trying to characterize more fully which cell types can be generated from these stem cells. Can they be switched into nerve cells only? We need to find this out. We're also interested in determining the difference between adult dental pulp stem cells and those in deciduous teeth."

Human Genome Mapping Completed – Two Years Early

The International Human Genome Sequencing Consortium, led in the United States by the National Human Genome Research Institute and the Department of Energy, has announced the successful completion of the Human Genome Project more than two years ahead of schedule.

The research institute also unveiled its bold new vision for the future of genome research, officially ushering in the era of the genome. The vision was published in the April 24 issue of the journal Nature, coinciding with the 50th anniversary of Nature's publication of the landmark paper that described DNA's double helix.

The international effort to sequence the 3 billion DNA letters in the human genome is considered by many to be one of the most ambitious scientific undertakings of all time.

"The Human Genome Project has been an amazing adventure into ourselves, to understand our own DNA instruction book, the shared inheritance of all humankind," said Genome Research Institute Director Francis S. Collins, MD, PhD, leader of the Human Genome Project. "All of the project's goals have been completed successfully -- well in advance of the original deadline and for a cost substantially less than the original estimates."

Aristides Patrinos, PhD, director of the Department of Energy's Office of Biological and Environmental Research in the Office of Science, said, "Sequencing the human genome was a pioneering venture with risks and uncertainties. But its success has created a revolution -- transforming biological science far beyond what we could imagine. We have opened the door into a vast and complex new biological landscape. Exploring it will require even more creative thinking and new generations of technologies."

The flagship effort of the Human Genome Project has been producing the reference sequence of the human genome. The international consortium announced the first draft of the human sequence in June 2000. Since then, researchers have worked tirelessly to convert the "draft" sequence into a "finished" sequence.

The finished sequence produced by the Human Genome Project covers about 99 percent of the human genome's gene-containing regions, and it has been sequenced to an accuracy of 99.99 percent. The sequence data generated by the Human Genome Project has been swiftly deposited into public databases and made freely available to scientists around the world, with no restrictions on its use or redistribution.

To spur the acceleration of medical research, the Genome Research Institute's "A Vision for the Future of Genomics Research" sets forth a series of challenges intended to energize the scientific community in using the newfound understanding of the genome to uncover the causes of disease and to develop bold new approaches to the prevention and treatment of disease. The plan was the outcome of more than a year of intense discussions with nearly 600 scientific and public leaders from government, academia, nonprofit organizations and the private sector.

Many of the challenges in the vision are aimed at utilizing genome research to combat disease and improve human health. The recommendations include calls for researchers to work toward:

- New tools to allow discovery in the near future of the hereditary contributions to common diseases, such as diabetes, heart disease and mental illness;
- New methods for the early detection of disease;
- New technologies that can sequence the entire genome of any person for less than $1,000; and
- Wider access to tools and technologies of "chemical genomics" to improve the understanding of biological pathways and accelerate drug discovery.

Additional information can be found at www.genome.gov.

Correction

Morris S. Clark, DDS, was inadvertently left off as a co-author with Stanley F. Malamed, DDS, of "Nitrous Oxide-Oxygen: A New Look at a Very Old Technique," which appeared on Page 397 of the May 2003 issue of the Journal of the California Dental Association.

Our apologies to Dr. Clark.

California Dental Board Approves OSAP for C.E.

The Dental Board of California has named the nonprofit Organization for Safety and Asepsis Procedures a registered continuing education provider. California residents who attend OSAP programs or complete OSAP C.E. exams can now earn credit hours that are approved through the state. The approval is granted through February 2005.

"We are so pleased to have our educational program and materials approved for C.E. credit in California," said OSAP executive director Therese Long, CAE. "California dental workers have been so loyal to OSAP; in addition to receiving top-notch infection control and safety information, they can also receive credit toward maintaining their licenses and certifications."

Information on OSAP conferences, newsletters, training programs, and other C.E. offerings is available at www.osap.org.

Nearly a Million Children Were Abused in 2001

An estimated 903,000 children across the country were victims of abuse or neglect in 2001, according to national data released by the Department of Health and Human Services. The statistics indicate that about 12.4 out of every 1,000 children were victims of abuse or neglect, a rate comparable to the previous year's rate of 12.2 out of 1,000 children.

"A nation as compassionate as ours should ensure that no child is a victim of abuse or neglect. The number of children that are being abused and neglected in this country is an unacceptable daily tragedy," Health and Human Services Secretary Tommy G. Thompson said. "We must do more to protect our most vulnerable children."

As part of Health and Human Services' 2004 budget request, the Bush administration is proposing a new approach to protecting children in the child welfare system. Under the plan, states and tribes would have the option of using some money now designated solely for foster care to support a range of abuse-preventive services and programs. The proposal provides the flexibility and sustained financial support necessary to build programs for children and families aimed at preventing maltreatment and removal from home.

The data are based on information collected through the National Child Abuse and Neglect Data System. The data show that child protective service agencies received about 2,672,000 reports of possible maltreatment in 2001. There were 903,000 substantiated cases of maltreatment of children -- the majority of which involved cases of neglect. About 1,300 children died of abuse or neglect, a rate of 1.81 children per 100,000 children in the population.

The full report, "Child Maltreatment 2001," is available at www.calib.com/nccanch/prevmnth. A table of state and national child abuse and neglect victimization rates for 2000 and 2001 is available from the National Clearinghouse on Child Abuse and Neglect at (800) 394-3366 or by e-mail at nccanch@calib.com.

Oral Piercing: Patients Need the Hole Story

In addition to acting as an advocate for safe piercing, the dental profession also must inform patients about the risks involved with oral piercing, so that patients can make informed choices, wrote Jay T. Biber, DMD, in the January-February Northwest Dentistry, journal of the Minnesota Dental Association.

Biber noted that people considering oral piercing, as well as many parents, are increasingly seeking input from their dentists. The documented detrimental effects of oral piercings on some individuals' oral health make it difficult for dentists to condone these procedures, Biber said.

The risks should be presented in a factual, nonjudgmental manner so as not to close doors to patients who later might need assistance with complications arising from their piercings.

Biber said the most common oral piercing site is a vertical piercing through the midline of the tongue, anterior to the lingual frenum. The tongue may also be pierced multiple times, off-center or horizontally. These alternative sites increase the risk of nerve damage or hemorrhage.

The lip is the second most frequently pierced oral site, generally in the midline, but also sometimes off-center, Biber said. The cheeks and lingual or maxillary frenum are increasingly popular piercing sites.

Biber noted that a variety of complications resulting from oral piercings have been documented, including tissue hyperplasia, swelling and dysphagia, hypotensive collapse, tetanus, Ludwig's angina, hepatitis transmission, and bacterial endocarditis.

"Peer-piercing" is becoming increasingly popular, Biber noted; and this increases the risk of young people acquiring infectious diseases through inadequate sterilization, reusing of instruments, or sharing of oral jewelry.

Biber said that complications appear to occur relatively infrequently. However, the potential for serious medical consequences resulting from oral piercings has been documented and should be included as part of the process of informed consent prior to an oral piercing.

Sleepy Dental Patient May Be Clue to Health Problem

Patients who fall asleep in the dental chair may be presenting dentists with vital clues as to their health, wrote Leslie C. Dort, DDS, in the January 2003 Journal of the Canadian Dental Association.

Armed with knowledge of excessive daytime sleepiness, dentists can play a role in guiding patients toward crucial treatment. Excessive daytime sleepiness can be a symptom of several underlying disorders, Dort said. Recognizing the problem and referring patients for diagnosis can be lifesaving.

Sleepiness occurs in 5 percent to 13 percent of the general population, according to Dort. Falling asleep in the dentist's office may be a sign of excessive daytime sleepiness, he noted. Common causes are:

- Insufficient sleep syndrome or sleep deprivation;
- Sleep apnea syndrome (including upper airway resistance syndrome);
- Sedating medications;
- Withdrawal from stimulants;
- Narcolepsy;
- Psychiatric disorders;
- Idiopathic hypersomnia; and
- Periodic limb movement disorder.

According to Dort, dentists should be concerned about sleepy patients who may be a danger to themselves and others. A few moments of careful consultation could enable dentists to direct patients with excessive sleepiness toward treatment that might improve quality of life, decrease cardiovascular morbidity, and ultimately save lives, Dort said.

Although dentists are not trained to diagnose sleep disorders, Dort said, they are in a unique position as health professionals to recognize patients who suffer from a sleep disorder.

Pay Attention to Patients' Tobacco Use to Avoid Malpractice Claims

Substantial evidence exists that smoking can contribute to periodontal disease and bone loss, particularly during orthodontic treatment, wrote Elizabeth Franklin in the January/February 2003 issue of the Bulletin, publication of the American Association of Orthodontists.

The development or exacerbation of periodontal disease during orthodontic treatment is one of the most costly causes of loss in orthodontic malpractice cases, Franklin wrote. Consequently, several risk-management issues should be considered when treating patients who smoke or use tobacco products.

Franklin noted that dentists should first ask patients if they smoke or use tobacco products. Medical and dental history forms should also include questions about these habits.

If adult patients confirm they use tobacco products, Franklin said, they should be encouraged to quit. She suggested that dentists may also consider declining to treat these patients if it is determined that the tobacco use will result in a poor outcome.

For dentists who decide to treat smokers for orthodontics, Franklin recommended steps to protect against allegations of exacerbation of periodontal disease or the development of bone loss. Dentists should:

- Take excellent beginning records, including X-rays and photos;
- Learn as much as possible from the patient about prior periodontal problems and treatment;
- Make sure adult patients have a periodontal evaluation and discuss with them their ability to undergo orthodontic treatment;
- Have a thorough informed consent discussion with the patient and place a signed document in the patient's record;
- Take interim X-rays to clarify the health of bone structure as treatment progresses;
- Keep a close eye on the condition of the gingival tissue for signs of inflammation and other problems, and refer the patient when appropriate;
- Ask the patient about abnormal pain and continually check for abnormal mobility;
- Be sure the patient maintains a vigilant oral hygiene routine; and
- Consider the possibility of early termination of treatment at the first opportunity once a problem presents itself, not allowing the disease to exacerbate.

Franklin advised dentists to clearly document patient records regarding all these issues. This documentation, she said, can be used as a defense in any claims-handling process.

CDA JOURNAL, VOL 31, Nº6

Current Issues in Adhesive Restorative Dentistry

Edmond R. Hewlett, DDS

AUTHORS

Edmond R. Hewlett, DDS, is an associate professor and vice chair of the Division of Restorative Dentistry at the University of California at Los Angeles School of Dentistry.

It is difficult to imagine day-to-day dental practice without the ability to bond materials to enamel and dentin surfaces. It is equally hard to comprehend the breadth and depth of knowledge created in this area since Michael Buonocore's watershed paper on bonding acrylic to acid-etched enamel was published nearly 50 years ago. Adhesive materials pervade today's restorative dentistry armamentarium. The quality of adhesion to tooth structure and range of associated techniques have advanced to the degree that "biomimetic" and similar terms are finding their way into the restorative lexicon. The state-of-the-art is inching ever closer to the "holy grail," i.e., the ability to permanently graft bioactive enamel and dentin analogues to teeth in situ.

Myriad questions regarding the key element of adhesive techniques -- the restorative-tooth interface -- nonetheless remain to be answered. With each discovery or technological advance, a host of new issues is unearthed, driving scientists back to the lab bench to develop yet the next generation of adhesive alchemy. Central to this cycle is the extraordinary complexity of the aforementioned interface. Structural variability of tooth substrates alone, particularly that of dentin, is significant enough to render a reasonable technique successful on one tooth and unsuccessful on another. Add to this the range of host factors and biologic variability commonly encountered in our patients, and one is left in awe that adhesive dental materials perform as well as they do.

Adhesive restorative systems are not unlike other complicated tools (such as powerful software programs or professional digital cameras) in that full exploitation of their capabilities requires more than a cursory understanding of how they work. It is in this spirit that the following three articles addressing different aspects of adhesive restorative dentistry are respectfully submitted for your perusal.

The first article focuses on the restorative-tooth interface, reviewing many of the factors that influence its predictability and durability. Strategies for enhancing these qualities based on available scientific data are provided as well.

Procedural issues such as field isolation, pulp capping, and use of adjunctive products such as caries detector dyes and desensitizers are addressed in the second article. Influences of these aspects on the final outcome in adhesive restorative procedures are highlighted.

Glass ionomer cements -- an often-overlooked group in a resin-dominated market -- are reviewed in the final article. Rationale for incorporating these useful materials into common restorative procedures is provided.

The authors hope you will enjoy this issue and find the information useful and thought-provoking.

CDA JOURNAL, VOL 31, Nº6

Resin Adhesion to Enamel and Dentin: A Review

Edmond R. Hewlett, DDS

ABSTRACT This article reviews the current knowledge base regarding resin adhesion to enamel and dentin. A descriptive classification system for adhesive resin products as well as clinical considerations derived from the review are also presented to assist the clinician in the selection and application of these products.

AUTHORS

Edmond R. Hewlett, DDS, is an associate professor and vice chair of the Division of Restorative Dentistry at the University of California at Los Angeles.

Advances in dental material science continue to generate products with increasingly biomimetic and bioactive qualities, and restorative dentistry is a conspicuous beneficiary of this trend. Current restorative techniques are capable of producing lifelike function and appearance while maximizing both preservation and resistance to further destruction of tooth structure. Adhesive procedures, however, are typically associated with high technique-sensitivity due to the complexity of interactions between contemporary materials and enamel and dentin substrates. Furthermore, material properties are often mistakenly assigned greater significance than treatment planning and clinical technique in influencing the longevity of adhesive restorations. It is incumbent upon the clinician to be cognizant of these issues and to account for them to obtain consistently predictable outcomes.

This article reviews the current knowledge base regarding resin adhesion to enamel and dentin. A descriptive classification system for adhesive resin products as well as clinical considerations derived from the review are also presented to assist the clinician in the selection and application of these products.

The Substrates

Enamel

Enamel -- the hardest substance in the human body -- consists primarily of highly mineralized inorganic substance (95 percent to 98 percent by weight, mostly hydroxyapatite) arranged in a dense crystalline structure. Assuming normal tooth development, this composition allows for minimal inherent variability, rendering the effect of acid etching on enamel highly consistent from tooth to tooth and from patient to patient. It follows then that the fundamental technique for bonding resin to enamel has undergone minimal change since its introduction in 1955.[1] Acid etching produces a complex three-dimensional microtopography at the enamel surface, increasing not only its surface area but also its surface free energy, which in turn increases its wettability and capacity for adhesion.[2] Flow of adhesive resin into surface irregularities is thus facilitated, creating a durable, leakage-resistant interface upon polymerization.

Phosphoric acid of 30 percent to 40 percent concentration applied for 15 to 30 seconds[2] produces optimal enamel etch patterns and resin retention. Alternative conditioners (e.g., oxalic acid, maleic acid, EDTA) associated with the so-called "third-generation" dentin adhesives produce suboptimal etching of and adhesion to enamel.[3-5] These later disappeared from use, as the "total-etch" technique (simultaneous dentin and enamel etching with phosphoric acid) became the norm for resin bonding. Currently, however, self-etching primer products have emerged as alternatives to total-etch. The ability of these products to produce optimal resin-enamel adhesion is questionable,[6,7] but recent reports are encouraging.[8,9] Claims that cavity preparation with air abrasion or laser devices alters enamel such that acid etching is unnecessary for resin bonding have been countered by substantial evidence to the contrary.[10-14]

One commonly encountered exception to enamel's structural consistency should be noted. Unprepared enamel at the outer surface of the clinical crown is aprismatic, requiring light grinding prior to etching to obtain an optimal etch pattern.[15-19]

Dentin

Just as the relatively uneventful evolution of resin-enamel bonding reflects the static nature and structural consistency of enamel, the dynamic, variable nature of dentin poses significant challenges to developing predictable resin-dentin bonding techniques. Dentin's composition by weight -- 75 percent inorganic material (hydroxyapatite), 20 percent organic material (collagen, other noncollagenous compounds), and 5 percent water -- suggests a highly mineralized substance. The arrangement of these components (50 percent inorganic material and 50 percent organic material and water by volume),[20] however, makes it an inherently problematic resin bonding substrate as compared to enamel.

Other factors further complicate the issue. Dentinal tubules of vital teeth communicate directly with the pulp and house cellular extensions of odontoblasts. Unbonded regions of dentin beneath a restoration can permit sufficient tubular fluid movement under functional or thermal stress to distort afferent nerves in the pulp and elicit pain.[21] Dentinal fluid under positive pressure from the pulp may affect diffusion of monomers into etched dentin. This phenomenon will vary in the presence of vasoconstrictors from local anesthetics, however, which reduce intrapulpal pressure. The structural variability of dentin must also be considered. Peritubular dentin, the cylindrical lining of tubules, is more highly mineralized than intertubular dentin. Tubule density (tubules/mm^2) and diameter vary significantly such that tubules make up 1 percent of the dentin surface at the dentinoenamel junction and 22 percent near the pulp.[22] Intertubular dentin, rich in collagen fibrils and considered optimal for hybridization, occupies 96 percent of a cut dentin surface near the DEJ but only 12 percent near the pulp.[23,24] Sclerotic dentin, formed by either reactive or aging processes, is characterized by tubular occlusion via peritubular dentin apposition, rendering this substrate hypermineralized[25] and acid-resistant.[26,27] The "smear layer"[28] of debris formed during instrumentation of dentin acts as a barrier to the underlying substrate and must be modified or removed for resin bonding to occur. Thickness and tenacity of smear layer attachment to the underlying dentin surface is inconsistent.[29]

Considering these factors, the term "normal dentin" seems an oxymoron. Each factor listed will influence the response of dentin to acid etching and resin bonding such that the response will vary not only from patient to patient and tooth to tooth, but between regions of the same tooth. Clinicians must avoid complacency toward resin-dentin bonding induced by manufacturer claims of speed and ease for current products. Only through methodical and meticulous manipulation of these products can dentin variability be neutralized and durable adhesion of restorative resins to dentin be realized.

The Products

This discussion will focus on current product strategies for dentin adhesion inasmuch as their interaction with etched enamel is relatively uncomplicated. All currently available resin adhesives utilize the same fundamental process to establish adhesion to dentin:

* Acid demineralization of the dentin surface that alters or removes the smear layer, exposes collagen fibrils, and renders the surface highly permeable;

* Infiltration of the demineralized dentin surface with a reactive hydrophilic resin primer to produce a resin/dentin interdiffusion zone[30] and micromechanical attachment to dentin; and

* Stabilization of the hybrid layer with an overlay of low-viscosity, light-polymerizable resin that copolymerizes (chemically bonds) with both the primer and subsequently applied composite resin restoratives. Bis-GMA and HEMA are the predominant resins in these systems, but there are notable exceptions such as 4-META/MMA-TBB. These adhesives similarly share a common goal with respect to their clinical utilization: a completely "hybridized," hermetically sealed resin/dentin interface with bond strength adequate to resist both immediate (composite polymerization shrinkage) and long-term (thermal expansion and contraction) stresses at the resin-dentin interface. Specific strategies for accomplishing dentin bonding vary widely within this framework, however, as indicated by the extensive and ever-changing array of products marketed for this purpose. In any event, discontinuities in the bonded interface can compromise results and lead to premature restoration failure, regardless of the properties of restorative material placed on the interface. Strict adherence to evidence-based protocols for utilization of adhesive systems is critical to predictability and longevity.

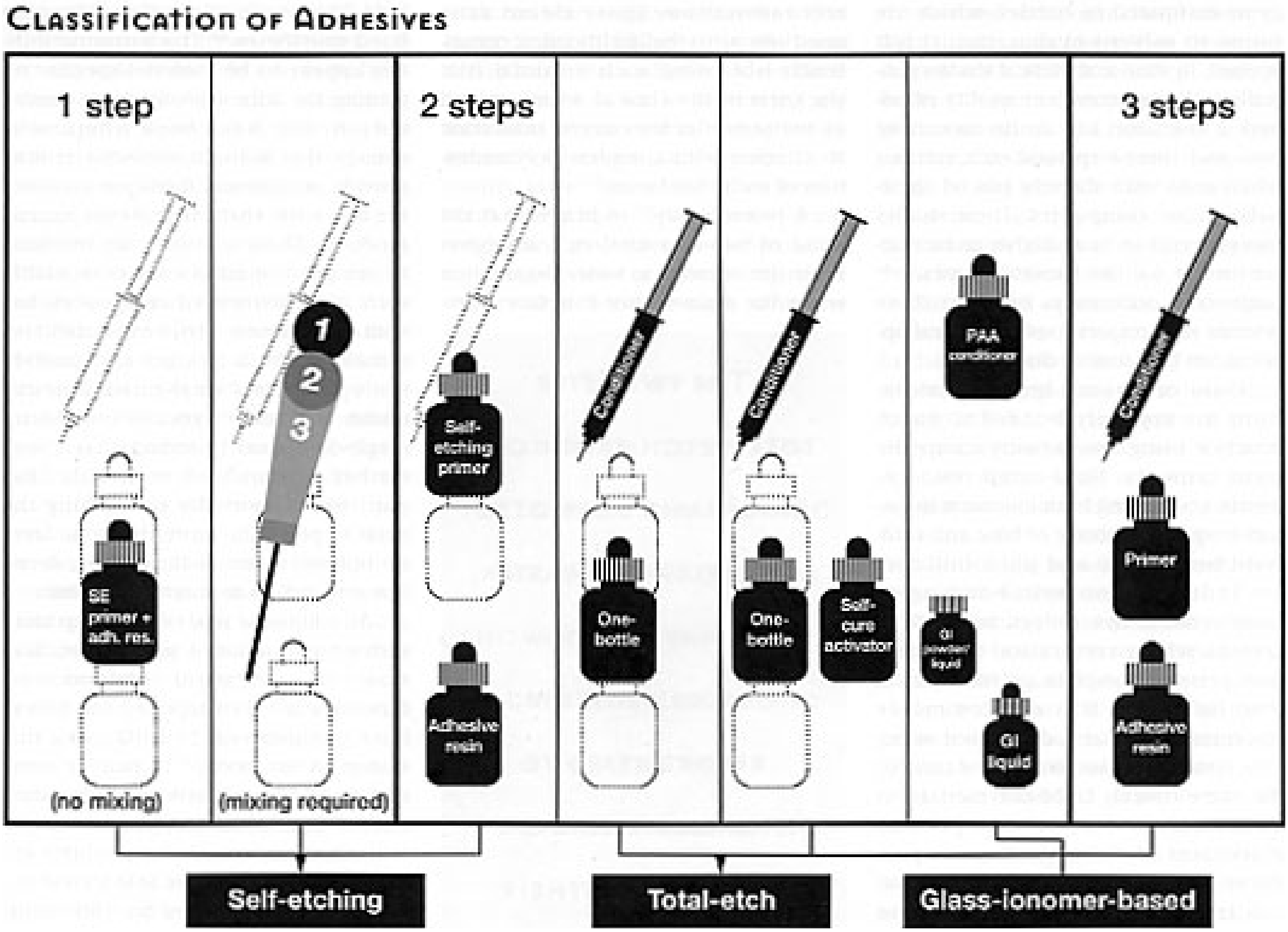


Figure 1. Classification of adhesives based on the number of clinical application steps and the type of substrate conditioning (self-etch or total-etch) employed. GI = glass ionomer, PAA = polyalkenoic acid (adapted from Van Meerbeek and colleagues[33]).

Adhesive resins are commonly classified according to their position in the chronology of historical development (e.g., "third-generation," "fourth-generation," "fifth-generation," etc.).[31,32] An objective, more descriptive classification by Van Meerbeek and colleagues groups current products according to the steps involved in their clinical use and their mode of interaction with the dentin substrate.[33,34] A modified version of this classification is presented here; an adhesive product is assigned to one of three groups according to the number of clinical steps it requires (one, two, or three), then subdivided according to whether it employs total etching or self-etching (Figure 1).

Total-etch adhesive systems utilize 30 percent to 40 percent phosphoric acid to simultaneously produce the desired effects on enamel (etch pattern) and dentin (smear removal, collagen exposure, increased permeability), followed by application of primer (hydrophilic resin) and adhesive resin or "bonding agent." Three-step (aka multiple-component or fourth-generation) total-etch systems consist of separate primer and resin components applied in consecutive steps following etching. Newer two-step (aka single-component, one-bottle, or fifth-generation) total-etch systems package primer and adhesive resin as one component for simultaneous application following etching. These simplified systems have been enthusiastically embraced by practitioners as evidenced by the sheer number of two-step products on the market. Unit-dose delivery of many two-step adhesives facilitates compositional consistency as compared to bottles, which are prone to solvent evaporation if left opened. In vitro and clinical studies generally indicate equivalent quality of adhesion to enamel and dentin for current two- and three-step total etch systems when used with directly placed light-polymerized composites. These studies also generally indicate higher technique-sensitivity for the two-step types.[35-41] Additional differences between these systems with respect to other clinical applications bear further discussion.

Resin or ceramic indirect restorations are typically bonded to tooth structure using low-viscosity composite resin cements. Dual-cured resin cements, containing both chemical initiators (requiring mixing of base and catalyst components) and photoinitiators are indicated for resin bonding of translucent inlays, onlays, and (some) crowns where restoration thickness may prevent complete polymerization with light only. It is also commonly recommended that a dual-cured adhesive system be used in these cases for the same reason. Light-polymerization of the adhesive resin layer prior to placement of the resin cement produces optimal fixing/hardening of hybridized dentin and higher bond strengths to dentin, but the adhesive film thickness may interfere with complete seating of the restoration.[42] Dual-cured adhesives, as with dual-cured cements, are not polymerized with light until the restoration is seated, with the chemical initiators again ensuring polymerization in deep areas. Many three-step total-etch systems include an optional dual-cure activator for this purpose, while classic two-step systems are light-polymerizable only, limiting their use to direct restorations.

Several manufacturers have in recent years marketed two-step total etch adhesives claiming a film thickness (less than 20 microns) that allows light-polymerization prior to seating an indirect restoration. These claims raise questions as to the likelihood of consistently obtaining such minimal film thickness in the clinical setting as well as the potential for oxygen inhibition to interfere with complete polymerization of such thin layers.

A recent study[43] indicates that the bond of two-step total-etch adhesives to dentin is prone to water degradation when the resin-dentin interface is exposed to the oral cavity, and that these products are more susceptible than their three-step counterparts in this regard. The study further demonstrates that a bonded resin-enamel margin completely surrounding the resin-dentin interface provides effective protection from this water degradation.

Two-step total-etch adhesives have been shown to bond inconsistently to autopolymerized ("self-cured") composite resins such as those used for foundation restorations ("cores") under fixed prostheses.[44] The incompatibilities appear to be material-specific regarding the adhesive/composite combination, but have been ubiquitous enough that many manufacturers now provide an optional dual-cure activator for use with their single-component products. These activators are intended to render the adhesives compatible with autopolymerized composites, but some isolated incompatibilities remain.[45] The activators also provide the option for a dual-cured adhesive under an indirect restoration. Many single-component products have been further reformulated to include filler particles, purportedly eliminating the need to place the more than one layer for optimal dentin sealing. These developments reflect an interesting trend: the two-step total-etch products, originally promoted as simpler and faster, have been incrementally reformatted to emulate more qualities of their versatile three-step predecessors.

An additional type of three-step total-etch system utilizes a unique combination of chemical compounds. Nakabayashi[30] first reported the hybrid layer phenomenon in 1982 using this system. A solution of 10 percent citric acid and 3 percent ferric chloride etches enamel and dentin, followed by 4-META (4-methacryloyloxyethyl trimellitate anhydride) dissolved in MMA (methyl methacrylate) initiated by TBB (tri-n-butyl borane) - 4-META/MMA-TBB. The ferric sulfate is thought to cross-link proteins in the collagen matrix, immobilizing them and thus preventing collagen collapse. Maintaining a moist dentin surface is therefore unnecessary.[46,47] A literature review of 4-META adhesives describes them as producing excellent results, being easy to use, not being technique-sensitive, and (unlike other systems) essentially retaining the same ingredients used since their introduction.[46]

Self-etching adhesive systems utilize an acidic primer to detach or dissolve the dentinal smear layer and demineralize the dentin surface to simultaneously expose and hybridize collagen fibers. A separate etching step is not used, nor is the self-etching primer rinsed off, thus streamlining the process. Two-step self-etching systems include a separate light-polymerized adhesive resin component placed after applying and drying the primer. One-step (aka "all-in-one") versions accomplish all three steps of resin-dentin bonding (etch/prime/bond) simultaneously with a single liquid. In addition to genuinely simplifying dentin bonding, self-etching is arguably a less technique-sensitive process than total etching. Rinsing and drying of etched dentin prior to hybridization are eliminated, neutralizing the issue of dentin wetness/dryness (see below). Additionally, depth of etching does not exceed depth of primer infiltration, preventing overetching and unhybridized dentin. Depth of demineralization in enamel and dentin is shallower with self-etching primers than with phosphoric acid. Microscopic features of the hybrid layer and bond strengths to dentin are nonetheless similar to those seen with total-etch systems.[48] An exception to this trend is sclerotic dentin, where a self-etching primer was shown not to etch beyond the hypermineralized surface layer.[49]

Ability of self-etching primers to produce optimal enamel adhesion was doubted initially,[6,7] prompting recommendations to selectively treat enamel with phosphoric acid when using these systems. More-recent in vitro studies report tensile and shear bond strength values on enamel similar to, albeit less consistent than, those obtained with phosphoric acid.[8,9] This difference is perhaps explained by the deeper interprismatic etch pattern produced by phosphoric acid as opposed to self-etching primers and the tendency of the latter to bond less tenaciously to unprepared vs. roughened enamel.[50] Use of a self-etching system following phosphoric acid etching was shown to significantly increase enamel bond strength, but bond strength to dentin was significantly decreased.[9]

It has been suggested that the initial (as opposed to 24-hour) tensile bond strength of a resin adhesive to dentin is an important factor in preventing gap formation at the dentin/restorative interface.[51] A recent study[52] reports significantly lower immediate microtensile bond strengths for several self-etching, single-step adhesives as compared to values obtained for a three-step total-etch control. Bond strength values for the single-step adhesives were in some cases only slightly higher than the 20 MPa[51] considered necessary for a gap-free interface. The study raised additional concerns regarding single-step adhesives in situations where polymerization of the composite resin restorative is delayed for two to three minutes after placement. Permeability of these adhesives was found to allow water diffusion from the underlying dentin into the interface between the adhesive and the uncured composite. Bond strengths were significantly lower than those produced with the three-step control under the same conditions. While this phenomenon should not affect a typical direct restoration where composite is placed and immediately polymerized, the authors of this study recommend that multiple direct or indirect restorations be individually light-activated immediately after application of composite restorative or cement. The authors further recommend avoiding the use of self-etching single-step adhesives when luting indirect restorations or posts with a dual-cure resin cement. Delay of light activation while removing excess cement may allow diffusion of dentinal fluid into the adhesive/cement interface and result in a diminished bond between these layers.

Self-etching systems show promise for routine bonding to tooth structure in a simplified manner. Additional clinical evidence of their ability to consistently produce durable adhesion to enamel and dentin, however, is clearly needed.

A resin-modified glass-ionomer adhesive (Fuji Bond LC, GC) for use in direct composite resin restorations is available in addition to the adhesive resins. As with self-etching primers, this strategy utilizes a less aggressive approach than phosphoric acid for attachment to tooth substrates. Conditioning of the prepared dentin surface with a polyalkenoic acid (25 percent polyacrylic acid) removes smear layer debris, permitting chemical adhesion of the resin-modified glass-ionomer cement adhesive to the underlying dentin substrate. In general, combined used of glass-ionomer cements and composite restoratives has demonstrated improved microleakage resistance at dentin margins (see "sandwich technique" below). A clinical trial of adhesively retained Class V composite restorations bonded with Fuji LC Bond reports an overall retention rate of 96 percent, with 20 percent of restorations available at five years displaying margin discoloration.[53] More longitudinal clinical data is needed.

The array of currently available dental adhesive products reflects a dynamic area of research and development aimed at technique simplification and clinical permanence. While newer product types hold promise for achieving these goals, it is the author's opinion that the three-step total-etch systems presently possess the most favorable levels of technique-sensitivity, clinical predictability, and range of application.

Clinical Technique Considerations

The foregoing information clearly illustrates the complex nature of resin adhesion in dentistry. The following techniques are provided to mollify the effects of high substrate and product variability inherent in resin bonding.

Overetching

Overetching of dentin can potentially occur with prolonged phosphoric acid contact. Denatured collagen resulting from excessive etching may compromise bond longevity.[47,54] Primers may additionally be unable infiltrate the full depth of a deep demineralized zone, leaving an unhybridized collagen band, which may also give rise to premature bond failure.[55-57] Dentin should typically be etched for no more than 15 seconds. Self-etching primer systems eliminate this consideration, as previously mentioned.

Sclerotic Dentin

Sclerotic dentin is atypically dense and hypermineralized and as such is resistant to acid etching. Self-etching primers are relatively ineffective on this substrate.[49] Removal of the surface layers with rotary instrumentation or use of extended etching times are common strategies for improving bonding to highly sclerotic dentin. However, even these approaches cannot guarantee improvement given sclerotic dentin's unique qualities.[58]

Moist vs. Dry Dentin

Drying of acid-etched dentin allows collagen fibers to collapse into a dense layer that resists penetration of primer resins.[59,60] The desired effect of acid etching -- increased permeability -- is thus potentially lost. Sensitivity to this issue varies with respect to the solvent type used for the primer resin. Acetone-based primers are critically dependant on a moist dentin surface for hybridization. Acetone displaces water in the interfibrillar spaces of the collagen network, carrying with it the hydrophilic resin needed for hybridization. Water-based primers, on the other hand, are the least sensitive to dentin dryness, demonstrating the ability to self-wet a dried dentin surface, separating the collapsed collagen fibers, and enabling resin diffusion into the network.[61] Ethanol-based primers display intermediate dependency on moist dentin.

As moist dentin is compatible with all

primer types, it is recommended that a moist dentin surface be routinely established for resin-dentin bonding with total-etch products. Avoid drying with compressed air after rinsing away etchant. Use high-volume evacuation to remove gross excess water, then blot remaining pooled water on the dentin surface with gauze or sponge applicators to leave dentin optimally moist.62 Overwet dentin (pooling of water) must also be avoided as excess water will dilute resin primer and out-compete it for sites in the collagen network, preventing hybridization.63 Overdried dentin should be rewet and blot-dried before applying primer. Rewetting etched, dried dentin for 30 seconds with water or 35 percent HEMA is effective for hydrating and re-expanding the collapsed collagen network.64,65

The "10-3" etching solution used in conjunction with 4-META adhesives, as mentioned previously, prevents collagen collapse and permits resin diffusion without moistening the dentin surface.46,47 The 3 percent ferric chloride component of this solution is also believed to provide protection against the bond-reducing effects of denatured collagen produced by acid-etching of dentin.54

Primer application to etched dentin must be performed with care. Primer or primer/adhesive solutions should only be dispensed immediately prior to application to avoid solvent evaporation. Bottle containers must be recapped immediately after dispensing for the same reason, with acetone-based products being particularly susceptible to evaporation. Primers generally benefit from extended application time as diffusion of monomers into dentin is time-dependant.66 Acetone-based three-step total-etch systems are thus placed with multiple applications of primer (four to five) without drying between applications. This technique provides more diffusion time, prevents evaporation of acetone before diffusion is completed, and accounts for the high dilution factor of the primer. Regarding two-step total-etch systems, many manufacturers indicate that a single coat of the primer/adhesive is adequate, but some studies report significant improvement of bond strength for these products when the manufacturer's protocol is doubled.67 Light agitation of primers or primer/adhesives can enhance diffusion into demineralized dentin, particularly with higher-viscosity filled adhesives. Forceful scrubbing, however, should be avoided. Finally, residual solvent may act as a contaminant and adversely effect bonding. Solvent must be thoroughly evaporated with a gentle stream of compressed air.68 Avoid a forceful air blast as it may displace resin. Acetone- and ethanol-based primers dry readily whereas drying water-based products may require a few more seconds. Hybridized dentin will appear shiny -- additional primer or primer/resin should be applied if dull areas are evident after drying.

Minimizing interfacial stresses during the restoration placement as well as over the long term is essential to preserving the bonded interface so painstakingly produced up to this point. Disruption of (as well as discontinuities in) the interface can allow fluid movement in unbonded tubules, producing pain under functional load temperature extremes. Suboptimal bonding at margins allows microleakage, causing sensitivity and secondary caries.

Stresses produced by polymerization shrinkage are of immediate concern. Incremental placement of composite resin has long been recognized as an effective strategy in this regard, using an initial increment of minimal thickness. Additionally, the concept of reducing interfacial stresses either with thicker, partially filled layers of bonding resin69,70 or by adding an intermediary layer of low elastic modulus71,72 has generated considerable interest in recent years. Low-viscosity (flowable) composite resin is frequently used for this purpose, as it potentially provides immediate as well as lasting stress absorption to prevent interfacial rupture. Additionally, manufacturers seek to impart adhesive systems with high immediate bond strength levels such that they can withstand composite shrinkage stress.

An entirely different strategy avoids resin-dentin bonding in areas at higher risk for postoperative sensitivity (medium-to-large Class I and II composite restorations) or microleakage (margins lacking enamel). The "sandwich technique" employs resin-modified glass-ionomer restorative as a base (dentin replacement) laminated with composite resin (enamel replacement). Glass ionomer produces a chemical bond to dentin following a non-invasive conditioning of the surface and displays superior resistance to caries at dentin margins as compared to resin bonding. Elimination of etching dramatically reduces the likelihood of postoperative sensitivity, and restoration stiffness is reduced with a concomitant increase in stress absorption capacity.34 The "open sandwich" option leaves glass ionomer exposed as the cervical portion of the final restoration when cervical margins terminate on dentin.

Other techniques such as directed polymerization shrinkage73 and use of light-reflecting wedges, both intended to reduce cervical margin gaps by inducing shrinkage toward the margin, are no longer considered valid in light of current understanding of resin shrinkage dynamics.74-76

Summary

Resin adhesion to tooth structure is a complex entity demanding thoughtful utilization of available systems to fully exploit their capabilities. The extraordinary range of materials and techniques available for resin-dentin bonding in particular is indicative of this complexity and of the degree to which questions regarding resin-dentin interface remain to be answered.

References

1. Buonocore MG, A simple method for increasing the adhesion of acrylic filling materials to enamel surfaces. *J Dent* Res 34:849, 1955.
2. Anusavice KJ, Structure of matter and principles of adhesion. In Phillips' Science of Dental Materials, 10th ed. WB Saunders Co, Philadelphia, 1996.
3. Reifeis PE, Cochran MA, Moore BK, An in vitro shear bond

strength study of enamel/dentin bonding systems on enamel. Oper Dent 20:174-9, 1995.
4. Swift EJ, Cloe BC, Shear bond strengths of new enamel etchants. Am *J Dent* 6:162-4, 1993.
5. Perdigao J, Lopes M, Dentin bonding -- questions for the new millennium. J Adhes Dent 1(3):191-209, 1999.
6. Ferrari M, Mannocci F, et al, Effect of two etching times on the sealing ability of Clearfil Liner Bond 2 in Class V restorations. Am *J Dent* 10:66-70, 1997.
7. Opdam NJ, Roeters FJ, et al, Marginal integrity and post operative sensitivity in Class II resin composite restorations in vivo. *J Dent* 26:555-62, 1998.
8. Shimada Y, Senawongse P, et al, Bond strength of two adhesive systems to primary and permanent enamel. Oper Dent 27(4):403-9, 2002.
9. Torii Y, Itou K, et al, Effect of phosphoric acid etching prior to self-etching primer application on adhesion of resin composite to enamel and dentin. Am *J Dent* 15(5):305-8, 2002.
10. Mulcahey K, Caputo AA, Duperon DF, In vitro bracket bond strength to acid-etched or air-abraded enamel. *Pediatr Dent* 21:281-4, 1999.
11. Nikaido T, Kataumi M, et al, Bond strengths of resin to enamel and dentin treated with low-pressure air abrasion. Oper Dent 21:218-24, 1996.
12. Borsatto MC, Catirse AB, Shear bond strength of enamel surface treated with air-abrasive system. Braz Dent J 13:175-8, 2002.
13. Usumez S, Orhan M, Usumez A, Laser etching of enamel for direct bonding with an Er,Cr:YSGG hydrokinetic laser system. Am *J Orthod* Dentofacial Orthop 122(6):649-56, 2002.
14. De Munck J, Van Meerbeek B, et al, Micro-tensile bond strength of two adhesives to Erbium:YAG-lased vs. bur-cut enamel and dentin. Eur J Oral Sci 110(4):322-9, 2002.
15. Gwinnett AJ, Interactions of dental materials with enamel. Trans Acad Dent Mater 3:30, 1999.
16. Ripa, LW, Gwinnett, AJ, Buonocore MG, The "prismless" outer layer of deciduous and permanent enamel. Arch Oral Biol 11:41-8, 1966.
17. Nathanson D, Bodkin JL, Evans JR, SEM of etching patterns in surface and subsurface enamel. J Pedodont 7:11-17, 1982.
18. Meola MT, Papaccio G, A scanning electron microscope study of the effect of etching time and mechanical pre-treatment on the pattern of acid etching on the enamel of primary teeth. Int Dent J 36:49-53, 1986.
19. Whittaker DK, Structural variations in the surface zone of human tooth enamel observed by scanning electron microscopy. Arch Oral Biol 27:383-92, 1982.
20. Mjör IA, Fejerskov O, eds, Human Oral Embryology and Histology, 1st ed. Munksgaard, Copenhagen, 1986.
21. Brännström M, Johnson G, Nordenvall K-J, Transmission and control of dental pain: resin impregnation for the desensitization of dentin. *J Am Dent Assoc* 99:612-8, 1979.
22. Pashley DH, Dentin: a dynamic substrate -- a review. Scanning Microsc 3:161-76, 1989.
23. Garberoglio R, Brännström M, Scanning electron microscopic investigation of human dentin tubules. Arch Oral Biol 21:355-62, 1976.
24. Pashley DH, Interactions of dental materials with dentin. Trans Acad Dent Mater 3:55, 1990.
25. Vasiliadis L, Darlin AI, Levers GH, The histology of sclerotic human root dentin. Arch Oral Biol 28:693-700, 1983.
26. Nakajima M, Sano H, et al, Tensile bond strength and SEM evaluation of caries-affected dentin using dentin adhesives. *J Dent* Res 74:1679-88, 1995.
27. Yoshiyama M, Carvalho RM, et al, Regional bond strengths of resins to human root dentin. *J Dent* 24:435-42, 1996.
28. Eick JD, Wilko RA, et al, Scanning electron microscopy of cut tooth surfaces and identification of debris by use of the electron microprobe. *J Dent* Res 49:1359-68, 1970.
29. Pashley DH, Smear layer: an overview of structure and function. Proc Finn Dent Soc 88:215, 1992.
30. Nakabayashi N, Kojima K, Masuhara E, The promotion of adhesion by the infiltration of monomers into tooth substrates. J Biomed Mater Res 16(3):265-73, 1982.
31. Kugel G, Ferrari M, The science of bonding: from first to sixth generation. *J Am Dent Assoc* 131 Suppl:20S-25S, 2000.
32. Freedman G, Leinfelder K, Seventh-generation adhesive systems. Dent Today 21(11):106-11, 2002.
33. Van Meerbeek B, Perdigao J, et al, The clinical performance of adhesives. *J Dent* 26:1-20, 1998.
34. van Meerbeek B, Inoue S, et al, Enamel and dentin adhesion. In Summitt JB, Robbins JW, et al, eds, Fundamentals of Operative Dentistry -- A Contemporary Approach, 2nd ed. Quintessence Publishing, Chicago, 2001.
35. Miyazaki M, Onose H, Moore BK, Effect of operator variability on dentin bond strength of two-step bonding systems. Am *J Dent* 13(2):101-4, 2000.
36. Gwinnett AJ, Dentin bond strengths after air-drying and re-wetting. Am *J Dent* 7:144-8, 1994.
37. Tay FR, Gwinnett AJ, Wei SHY, Ultrastructure of the resin-dentin interface following reversible and irreversible rewetting. Am *J Dent* 10:77-82, 1997.
38. Perdigao J, Ramos JC, Lambrechts P, In vitro interfacial relationship between human dentin and one-bottle dental adhesives. Dent Mater 13(4):218-27, 1997.
39. Medina V 3rd, Shinkai K, et al, Effect of bonding variables on the shear bond strength and interfacial morphology of a one-bottle adhesive. Oper Dent 26(3):277-86, 2001.
40. Eliades G, Vougiouklakis G, Palaghias G, Heterogeneous distribution of single-bottle adhesive monomers in the resin-dentin interdiffusion zone. Dent Mater 17(4):277-83, 2001.
41. Van Meerbeek M, Vargas M, et al, Adhesive cements to promote preservation dentistry. Oper Dent 26(Supl. 6):S119-S144, 2001.
42. Hahn P, Schaller H, et al, Effect of different luting procedures on the seating of ceramic inlays. J Oral Rehabil 27(1):1-8, 2000.
43. De Munck J, Van Meerbeek B, et al, Four-year water degradation of total-etch adhesives bonded to dentin. *J Dent* Res 82:136-40, 2003.
44. Sanares AM, Itthagarun A, et al, Adverse surface interactions between one-bottle light-cured adhesives and chemical-cured composites. Dent Mater 17(6):542-56, 2001.
45. O'Keefe KL, Powers JM, Adhesion of resin composite core materials to dentin. Int J Prosthodont 14(5):451-6, 2001.
46. Chang JC, Hurst TL, et al, 4-META use in dentistry: A literature review. J Prosth Dent 87:216-24, 2002.
47. Nakabayashi N, Nakamura M, Yasuda N, Hybrid layer as a dentin-bonding mechanism. J Esthet Dent 3(4):133-8, 1991.
48. Toledano M, Osorio R, et al, Influence of self-etching primer on the resin adhesion to enamel and dentin. Am *J Dent* 14(4):205-10, 2001.
49. Kwong SM, Cheung GS, et al, Micro-tensile bond strengths to sclerotic dentin using a self-etching and a total-etching technique. Dent Mater 18(5):359-69, 2002.
50. Perdigao J, Geraldeli S, Bonding characteristics of self-etching adhesives to intact versus prepared enamel. J Esthet Restor Dent 15(1):32-41, 2003.
51. Burrow MF, Tagami J, et al, Early tensile bond strengths of several enamel and dentin bonding systems. *J Dent* Res 73(2):522-28, 1994.
52. Tay FR, Pashley DH, et al, Single-step adhesives are permeable membranes. *J Dent* 30:371-82, 2002.
53. Tyas MJ, Burrow MF, Clinical evaluation of a resin-modified glass ionomer adhesive system: results at five years. Oper Dent 27(5):438-41, 2002.
54. Mizunuma T, Relationship between bond strength of resin to dentin and structural change of dentin collagen during etching. Influence of ferric chloride to the structure of collagen. J Jpn Dent Mater 5:54-64, 1986.
55. Sano H, Shono T, et al, Microporous dentin zone beneath resin-impregnated layer. Oper Dent 19:59-64, 1994.
56. Sano H, Takatsu T, et al, Nanoleakage: leakage within the hybrid layer. Oper Dent 20:18-25, 1995.
57. Sano H, Yoshikawa T, et al, Long-term durability of dentin bonds made with a self-etching primer. *J Dent* Res 78:906-11, 1999.
58. Kwong SM, Tay FR, et al, An ultrastructural study of the application of dentine adhesives to acid-conditioned sclerotic dentine. *J Dent* 28(7):515-28, 2000.
59. Pashley DH, Ciucchi B, et al, Permeability of dentin to adhesive agents. Quintessence Int 24:618-31, 1993.
60. Pashley DH, Carvalho RM, Dentine permeability and dentine adhesion. *J Dent* 25:355-72, 1997.
61. Van Meerbeek B, Yoshida Y, et al, A TEM study of two water-based adhesive systems bonded to dry and wet dentin. *J Dent* Res 77(1):50-9, 1998.
62. Goes MF, Pachane GCF, Garcia-Godoy F, Resin bond strength with different methods to remove excess water from the dentin. Am *J Dent* 10:298-301, 1997.
63. Tay FR, Gwinnett AJ, Wei SHY, Micromorphological spectrum from overdrying to overwetting acid-conditioned dentin in water-free, acetone-based, single-bottle primer/adhesives. Dent Mater 12:236-244, 1996.
64. Perdigao J, Frankenberger R, et al, New trends in dentin/enamel adhesion. Am *J Dent* 13(Spec No):25D-30D, 2000.
65. Finger WJ, Balkenhol M, Rewetting strategies for bonding to dry dentin with an acetone-based adhesive. J Adhes Dent 2(1):51-6, 2000.
66. Nakabayashi N, Saimi Y, Bonding to intact dentin. *J Dent* Res 75:1706-15, 1996.
67. Platt JA, Almeida J, et al, The effect of double adhesive application on the shear bond strength to dentin of compomers using three one-bottle adhesive systems. Oper Dent 26(3):313-7, 2001.
68. Jacobsen T, Ma R, Solderholm K-J, Dentin bonding through interpenetrating network formation. Trans Acad Dent Mater 7:45, 1994.
69. Kemp-Scholte KM, Davidson CL, Marginal integrity related to bond strength and strain capacity of composite resin restorative systems. J Prosthet Dent 64:658-64, 1990.
70. Van Meerbeek B, Willems G, et al, Assessment by nano-indentation of the hardness and elasticity of the resin-dentin bonding area. *J Dent* Res 72:1434-42, 1993.
71. Deliperi S, Bardwell DN, An alternative method to reduce polymerization shrinkage in direct posterior composite restorations. *J Am Dent Assoc* 133(10):1387-98, 2002.
72. Ernst CP, Cortain G, et al, Marginal integrity of different resin-based composites for posterior teeth: an in vitro dye-penetration study on eight resin-composite and compomer-adhesive combinations with a particular look at the additional use of flow-composites. Dent Mater 18(4):351-358, 2002.
73. Fusayama T, Biological problems of the light cured composite resin. Quintessence Int 24:225-26, 1993.
74. Perdigao J, Lambrechts P, et al, The interaction of adhesive systems with human dentin. Am *J Dent* 9:167-73, 1996.
75. Versluis A, Douglas WH, et al, Does an incremental filling technique reduce polymerization shrinkage stresses? *J Dent* Res 75:871-8, 1996.
76. Versluis A, Tantbirojn D, Douglas WH, Do dental composites always shrink toward the light? *J Dent* Res 77:1435-1445, 1998.

To request a printed copy of this article, please contact/ Edmond R. Hewlett, DDS, UCLA School of Dentistry, Box 951668, Los Angeles, CA 90095-1668.

Clinical Considerations in Adhesive Restorative Dentistry — Influence of Adjunctive Procedures

Edmond R. Hewlett, DDS, and Charles F. Cox, DMD, PhD

ABSTRACT Several adjunctive procedures commonly performed during placement of adhesively bonded restorations can significantly influence a restoration's immediate and long-term clinical performance and the maintenance of pulp vitality. This article reviews some of these procedures to highlight and characterize their potential effects on the restorative outcome and to offer suggestions for appropriately incorporating these procedures into routine clinical practice.

AUTHORS

Edmond R. Hewlett, DDS, is an associate professor and vice chair of the Division of Restorative Dentistry at the University of California at Los Angeles School of Dentistry.

Charles F. Cox, DMD, PhD, is an associate professor in the Division of Restorative Dentistry at UCLA School of Dentistry

The complexity of resin/tooth adhesion and its numerous consequences for managing typical restorative procedures have been addressed in another article.[1] In addition to issues related to inherent characteristics of the tooth substrates and adhesive systems, other variables merit consideration. Specifically, several adjunctive procedures commonly performed during placement of adhesively bonded restorations can significantly influence a restoration's immediate and long-term clinical performance and the maintenance of pulp vitality. This article reviews some of these procedures to highlight and characterize their potential effects on the restorative outcome and to offer suggestions for appropriately incorporating these procedures into routine clinical practice.

Isolation of the Operating Field

Despite improvements in dental cements and adhesive resins, one aspect of adhesive restorative dentistry remains constant: Prevention of contamination by saliva or blood during critical steps of restoration placement is key to achieving an optimum outcome. Use of a rubber dam is still widely regarded as the most effective method of moisture control, in addition to improving visibility and access, protecting patients from aspirating or swallowing small objects, and reducing microbial transmission from patients to dental personnel (Figure 1). Even high intraoral humidity has been shown to adversely affect resin-dentin bonding, prompting yet another recommendation for rubber dam use.[2,3] While some studies have suggested that survival of composite resin restorations is not necessarily enhanced by use of a rubber dam,[4]

Figure 1. The importance of effective isolation during adhesive restorative procedures cannot be overstated (photo courtesy of Dr. R.G. Stevenson, III).

the preponderance of opinion in this regard is to the contrary.5-8 Furthermore, rubber-dam isolation is not optional for air abrasion cavity preparation or CAD/CAM techniques, the latter involving direct optical imaging of prepared teeth for restoration with bonded ceramic. Evidence indicates that patients are generally not averse to rubber dam use and often prefer it for restorative procedures.9,10

Optional isolation methods include use of absorbent materials (cotton rolls, parotid shields) in conjunction with evacuator/retractor devices.11 Gingival retraction cord is also used in lieu of specialized rubber-dam retainers to improve isolation and access for cervical restorations. These methods are less effective than the rubber dam but may provide adequate moisture control in less demanding situations. In any event, field isolation during adhesive restorative procedures must be meticulously maintained.

Dealing With Contamination

The reality of day-to-day clinical practice is that saliva contamination during adhesive procedures will occasionally occur despite efforts to prevent it. It is therefore prudent to consider strategies for managing these occurrences based on interpretation of available scientific evidence. These strategies include utilizing indirect (ceramic, composite resin, cast gold) and/or nonresin-bonded alternatives (glass-ionomer restoratives and luting agents) if moisture control cannot be adequately established and maintained for direct resin procedures.

For resin bonding, it is recommended that saliva-contaminated etched enamel be rinsed, dried, and re-etched for 10 seconds.12,13 Acid-etched dentin, however, exhibits less sensitivity to saliva contamination, possibly due to the water content of saliva and the requirement of a moist dentin surface for optimum adhesion of many bonding resins.14-16 A one-second air blast to remove excess saliva without dehydrating the dentin produced bond strengths equivalent to those obtained with uncontaminated dentin.13 The long-term effect of biofilm incorporation at the dentin-resin interface under such circumstances has not been investigated.

Other reports indicate that bond strength to contaminated and re-etched dentin is similar to that for noncontaminated controls.17 In light of these various findings, it is the authors' recommendation that etched/contaminated enamel and dentin both be dried and re-etched for a maximum of 10 seconds, with selective application of the etchant first to enamel, if possible, to minimize the additional acid contact with dentin. The rationale is that reapplication of the acid to the dentin is likely to solubilize salivary contaminants and facilitate their removal with rinsing.

Adhesion of composite resin to dentin is significantly reduced if saliva contamination occurs after adhesive application. This result was obtained for contamination of adhesive with saliva both prior to and after polymerization.18 Saliva contaminants were not rinsed off in this study. Unpolymerized adhesive resin presumably acts as at least a partial barrier to direct saliva contact with etched enamel and dentin by virtue of its hydrophobic properties. Removal of saliva and resin with a compressed air blast followed by reapplication and polymerization of the resin is therefore recommended. An exception, however, is the hydrophilic primer component of multiple-bottle adhesives. It is not likely that these solutions fit the hydrophobic barrier hypothesis. These products should therefore be avoided in favor of single-component adhesives or nonresinous materials in situations at higher risk for saliva contamination.

Contamination after polymerizing either the adhesive resin or a composite resin increment has also been shown to reduce bond strength to subsequent increments17 as well as fracture toughness of the final restoration.19 Removal of salivary contaminants from polymerized resin surfaces is thus recommended. As simple drying seems to be inadequate,17 scrubbing of the contaminated and dried surface with adhesive resin followed by resin thinning/removal with compressed air is offered as an empirical recommendation.

Caries Detector Dyes

Characterization of dentinal caries has revealed a zone of demineralization at the advancing front of the lesion that precedes actual bacterial infection of the substrate.20 A technique for using a basic fuchsin red stain to differentiate between the infected dentin and the bacteria-free demineralized zone was developed in the late 1970s21 and has given rise to several protein dye products marketed for caries detection. Designed to dye denatured collagen, these indicators are purportedly useful for facilitating thorough caries removal while preventing unnecessary removal of non-infected demineralized dentin. They also aid visualization of remaining caries in minimally invasive cavities when tooth structure is preserved at the expense of convenience form.

In vitro studies indicate that use of these dyes does not significantly affect composite bonding to enamel and dentin.22,23 A review of caries detector dyes,24 however, cites several studies that call the accuracy of these agents into question. Of particular concern is a tendency for the dyes to render false positives along the dentinoenamel junction25 and at circumpulpal sites.26 This differential uptake of stain was explained by the higher proportion of organic matrix normally present in these areas.[26] Furthermore, due to lack of true specificity for caries among these dyes, absence of stain does not guarantee elimination of bacteria.

In light of these findings, clinicians are cautioned as to the potential for unnecessarily aggressive removal of dentin when a caries detector dye is used as the sole basis for this clinical decision.[24] The value of tactile and visual means for caries detection should not be discounted. This issue underscores the highly variable nature of dentin as a resin bonding substrate, and, in the authors' opinion, validates the routine use of the "sandwich technique" -- replacement of dentin with glass-ionomer -- in resin restorations involving deep caries excavations.[1,27]

Dentin Desensitizers

Various types of products are available for treatment of hypersensitivity associated with noncarious cervical lesions and gingival recession. Along with fluorides and oxalate crystal solutions, a third group of desensitizers can be described as dentin bonding derivatives. These typically consist of a hydrophilic resin primer (usually 35 percent HEMA) in solution with an antibacterial agent (chlorhexidine or benzalkonium chloride). In addition to topical application use, some of these derivatives are recommended by manufacturers for use in the total-etch dentin bonding protocol, typically applied to moist dentin between etching and priming, to reduce post-operative sensitivity. Anecdotal reports of their efficacy in this application are common, and this comes as no surprise. Application of these products to etched moist dentin is tantamount to priming, the additional antibacterial component notwithstanding. It is likely that a more thorough dentin hybridization is resulting, thus highlighting the importance of this critical step. It is also likely that the same effect can be obtained simply by extending the application time for the primer component of one's adhesive system of choice. In spite of the apparent compatibility of HEMA-containing desensitizers and adhesive systems, isolated examples of material-specific incompatibility have been reported.[28]

Cavity Disinfection

Treatment of cavity preparations with commercially available antibacterial solutions is purported to reduce the incidence of postoperative sensitivity by elimination of viable bacteria and their toxins from the restorative interface. Chlorhexidine and benzalkonium chloride are again the commonly used active ingredients. Modes of use vary: before etching, after etching, rinsing off or not rinsing. The obvious question of effect on resin bond to dentin and enamel has been addressed with in vitro studies. Reports reflect a highly material-specific nature to this issue with significant effects on bonding in some cases.[29,30] Use of a chlorhexidine cleanser before etching was shown not to affect bonding to enamel or dentin.[31] Another study, however, reported reduced dentin bond strengths when a chlorhexidine cleanser was used before or after etching, but rinsing the cleanser off before bonding produced bond strengths similar to no-cleanser controls.[32] Rinsing away cleansers prior to bonding will most likely prevent undesired material interactions.

Pulp Capping

Several classic direct pulp capping studies have reported on the biological success of calcium hydroxide ($Ca(OH)_2$)-containing materials to promote pulp healing.[33-38] Until the late-1980s, many researchers speculated on the unique capacity of $Ca(OH)_2$ to "stimulate" dentin bridge formation following a pulp exposure. Other studies since that time, however, have demonstrated that in the absence of bacterial contamination, many restorative materials are biologically compatible against exposed pulps and can provide an environment conducive to dentin bridge formation.[39-42]

Concerns over pulp injury during "total etching" of enamel and dentin with phosphoric acid during routine resin restorative procedures have long been dispelled.[43-48] The controversy of in vivo total etching and resin bonding of exposed pulps, however, continues.[49-52] Data citing deleterious effects on pulp are in disagreement with many other studies that have reported soft-tissue healing followed by eventual dentin bridge formation after direct capping with total etch and resin bonding.[39,47,49,50-57] Histologic and clinical data from these studies show that most adhesive systems are biologically comparable to $Ca(OH)_2$ when placed onto exposed vital pulps provided that proper hemorrhage control, cavity disinfection, and prevention of microleakage around the final restoration have been accomplished.

Dentin bridges have been reported to contain multiple tunnel defects that allow for the migration of $Ca(OH)_2$ particles and bacteria into the pulp tissues.[39,58] Persistence of these particles (along with microleakage) causes immediate inflammation, which may eventually lead to necrosis and periapical pathology. Gwinnett and Cox likened the persistence of these $Ca(OH)_2$ particles to the "passing of a bag of marbles down through successive generations of a family."[59] Additionally, the presence of resin globules in dentinal tubules and pulp tissues a few days after adhesive placement, and in giant cells of the pulp at 90 days, has been reported.[60] TEM data from this study are similar to that of others that showed phagocytosis of $Ca(OH)_2$ particles within various types of pulp cells subjacent to the exposure.[61]

Studies of pulp capping with different adhesive resin systems continue to convey varied findings, with some authors reporting poor-to-disastrous histological results and others reporting high rates of biological success with some of the same adhesive bonding systems. The cause of these disparate findings is unclear. One aspect of this dilemma is clear, however: When analyzing results from the numerous in vivo studies showing successful healing and dentin bridging, factors of technique-sensitivity continually emerge as most significant for the clinician to be aware of and manage.

Presence of dentin chip fragments and Ca(OH)2 particles62 and persistence of the coagulum-clot at the exposure site63 have been shown to disturb and alter the healing sequence of exposed dental pulps. Accordingly, the importance of cleaning the wound site to remove inflammation-producing debris and bacteria has been stressed.63-65 Effectiveness of a 3 percent to 5 percent solution of sodium hypochlorite (NaOCl) in this regard, as well as removing blood coagulum from pulp exposure sites, has been demonstrated.66-69 Furthermore, ongoing studies by Cox and colleagues indicate that proper clinical placement of a medical-grade NaOCl solution provides for control of pulp hemorrhage with no associated damage to the normal underlying tissues. The importance of hemorrhage control prior to adhesive resin bonding has been clearly shown.70 Presence of blood, pulp tissue exudates, or salivary proteins contaminating dentin will severely inhibit dentin-resin hybridization, allowing bacterial microleakage at the nonbonded interface, likely leading to pulp inflammation and eventual necrosis.

Summary

Procedural aspects of adhesive restoration placement can have greater influence on restoration longevity and pulp vitality than the choice of restorative materials used. Clinicians are urged to execute common adjunctive procedures such as those described here in an appropriate, meticulous manner to manage the technique-sensitivity inherent in adhesive restorative dentistry.

References

1. Hewlett ER, Resin adhesion to enamel and dentin: A review. *J Calif Dent Assoc* 31(6):469-82, 2003.
2. Besnault C, Attal JP, Influence of a simulated oral environment on dentin bond strength of two adhesive systems. Am *J Dent* 14(6):367-72, 2001.
3. Asmussen E, Peutzfeldt A, The influence of relative humidity on the effect of dentin bonding systems. J Adhes Dent 3(2):123-7, 2001.
4. Raskin A, Setcos JC, et al, Influence of the isolation method on the 10-year clinical behaviour of posterior resin composite restorations. Clin Oral Investig 4(3):148-52, 2000.
5. Marshall K, Rubber dam. Br Dent J 184(5):218-9, 1998.
6. Barghi N, Knight GT, Berry TG, Comparing two methods of moisture control in bonding to enamel: a clinical study. Oper Dent 16:130-5, 1991.
7. Christensen GJ, Using rubber dams to boost quality, quantity of restorative services. *J Am Dent Assoc* 125:81-2, 1994.
8. Knight TG, Barghi N, Berry T, Microleakage of enamel bonding as affected by moisture control methods. *J Dent* Res 70:561, 1991.
9. Gergely EJ, Rubber dam acceptance. Brit Dent J 167:249-52; 1989.
10. Stewardson DA, McHugh ES, Patients' attitudes to rubber dam. Int Endod J 35(10):812-9, 2002.
11. Van Meerbeek B, Inoue S, et al, Enamel and dentin adhesion. In Summitt JB, Robbins JW, Schwartz RS, Fundamentals of Operative Dentistry, A Contemporary Approach. Quintessence , Chicago, 2001.
12. Gwinnett AJ, Moist versus dry dentin: its effect on shear bond strength. Am *J Dent* 5:127, 1992.
13. Hormati AA, Fuller JL, Denehy GE, Effects of contamination and mechanical disturbance on the quality of acid etched enamel. *J Am Dent Assoc* 100:34-8, 1980.
14. Taskonak B, Sertgoz A, Shear bond strengths of saliva contaminated "one-bottle" adhesives. J Oral Rehabil 29(6):559-64, 2002.
15. Abdalla AI, Davidson C, Bonding efficiency and interfacial morphology of one-bottle adhesives to contaminated dentin surfaces. Am *J Dent* 11(6):281-5, 1998.
16. Johnson ME, Burgess JO, et al, Saliva contamination of dentin bonding agents. Oper Dent 19(6):205-10, 1994.
17. Powers JM, Finger WJ, Xie, Bonding of composite resin to contaminated human enamel and dentin. J Prosthodont 4:28-32, 1995.
18. Hitmi L, Attal JP, Degrange MJ, Influence of the time-point of salivary contamination on dentin shear bond strength of 3 dentin adhesive systems. Adhes Dent 1(3):219-32, 1999.
19. Dhuru VB, Lloyd CH, The fracture toughness of repaired composite. J Oral Rehabil 13(5):413-21, 1986.
20. Fusayama T, Okuse K, Hosoda H, Relationship between hardness, discoloration, and microbial invasion in carious dentin. *J Dent* Res 45:1033-46, 1966.
21. Kuboki Y, Liu CF, Fusayama T, Mechanism of differential staining in carious dentin. *J Dent* Res 62:713-4, 1983.
22. el-Housseiny AA, Jamjoum H, The effect of caries detector dyes and a cavity cleansing agent on composite resin bonding to enamel and dentin. J Clin *Pediatr Dent* 25(1):57-63, 2000.
23. Kazemi RB, Meiers JC, Peppers K, Effect of caries disclosing agents on bond strengths of total-etch and self-etching primer dentin bonding systems to resin composite. Oper Dent 27(3):238-42, 2002.
24. McComb D, Caries-detector dyes -- How accurate and useful are they? *J Can Dent Assoc* 66:195-8, 2000
25. Kidd EA, Joyston-Bechal S, Beighton D, The use of a caries detector dye during cavity preparation: a microbiological assessment. Br Dent J 174:245-8, 1993.
26. Yip HK, Stevenson AG, Beeley JA, The specificity of caries detector dyes in cavity preparation. Br Dent J 176:417-21, 1994.
27. Hewlett ER, Mount GJ, Glass ionomers in contemporary restorative dentistry -- A clinical update. J Cal Dent Assoc 31(7):483-93, 2003.
28. Seara SF, Erthal BS, et al, The influence of a dentin desensitizer on the microtensile bond strength of two bonding systems. Oper Dent 27(2):154-60, 2002.
29. Meiers JC, Kresin JC, Cavity disinfectants and dentin bonding. Oper Dent 21(4):153-9, 1996.
30. Tulunoglu O, Ayhan H, et al, The effect of cavity disinfectants on microleakage in dentin bonding systems. J Clin *Pediatr Dent* 22(4):299-305, 1998.
31. el-Housseiny AA, Jamjoum H, The effect of caries detector dyes and a cavity cleansing agent on composite resin bonding to enamel and dentin. J Clin *Pediatr Dent* 25(1):57-63, 2000.
32. Gurgan S, Bolay S, Kiremitci A, Effect of disinfectant application methods on the bond strength of composite to dentin. J Oral Rehabil 26(10):836-40, 1999.
33. Zander HA, Reaction of the pulp to calcium hydroxide. *J Dent* Res 18:373-9, 1939.
34. Phaneuf RA, Spencer FW, Morris RP, A comparative histological evaluation of the calcium hydroxide preparations on the human primary dental pulp. *J Dent* Child 34:61-7, 1968.
35. Stanley HR, Lundy T, Dycal therapy for pulp exposures. Oral Surg 37:818-27, 1972.
36. Tronstad L, Mjör IA, Pulpal reactions to calcium hydroxide containing materials. Oral Surg 33:961-5, 1972
37. Tronstad L, Reaction of the exposed pulp to dycal treatment. Oral Surg 36:945-53, 1974.
38. Heys DR, Cox CF, Heys RJ, Histological considerations of direct pulp capping. *J Dent* Res 60:1371-9, 1981.
39. Cox CF, Keall CL, et al, Biocompatibility of surface-sealed dental materials against exposed dental pulps. J Prosth Dent 57:1-8, 678, 1987.
40. Snuggs HM, Cox CF, et al, Pulpal healing and dentinal bridge formation in an acidic environment. Quint Int 24:501-10, 1993.
41. Kakehashi S, Stanley HS, Fitzgerald RJ, The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats. Oral Surg Oral Med Oral Path 20:340-9, 1965.
42. Brännström M, Dentin and Pulp in Restorative Dentistry. Dental Therapeutics AB, Nacka, Sweden, 1981, pp 67-128.
43. Fusayama T, Factors and prevention of pulp irritation by adhesive composite resin restorations. *J Dent* Res 18:633-41, 1987.
44. Inokoshi S, Iwaku M, Fusayama T, Pulpal response to a new adhesive restorative resin. *J Dent* Res 61:1014-9, 1982.
45. Cox CF, Biocompatibility of dental materials in the absence of bacterial infection. Oper Dent 12:146-52,1987.
46. Otsuki M, Histopathological study on pulpal response to restorative composite resins and their ingredients. J Jpn Stomat Soc 55:203-36, 1988.
47. Hosoda H, Inokishi S, et al, Pulp response to a new bonding agent and recently designed adhesive liners containing a salicylic acid derivative. Jpn J Conserv Dent 32:398-410, 1989.
48. Cox CF, Effects of adhesive resins and various dental cements on the pulp. Oper Dent 5:165-76, 1992.
49. Costa CAS, Hebling J, Teixeira MF, Preliminary study of biocompatibility of all bond 2 and scotchbond MP adhesive systems. Histological evaluation on subcutaneous implants in rats. Rev Odont USP 11:11-8, 1997.
50. Pereira JC, Segala AD, Costa CAS, Human pulp response to direct capping with an adhesive system: histologic study. Am *J Dent* 12:139-47, 2000.

51. Pameijer CH, Stanley HR, The disastrous effects of the "total etch" technique in vital pulp capping in primates. Am *J Dent* 11:45-54, 1998.
52. Hebling J, Giro EMA, Costa CA, Biocompatibility of an adhesive system applied to exposed human dental pulp. J Endod 25:676-82, 1999.
53. Otsuki M, Tagami J, Kanca J, Histologic evaluation of two Bisco adhesive systems on exposed pulps. *J Dent* Res 76:78, 1997.
54. Onoe N, Study on adhesive bonding systems as a direct pulp capping agent. Jpn J Conserv Dent 37:429-66, 1994.
55. Ebihara T, Katoh Y, Histopathological study on development of adhesive resinous material containing calcium hydroxide as direct pulp capping agent. Jpn J Conserv Dent 39:1288-315, 1996.
56. Akimoto N, Momoi Y, Kohno A, Biocompatibility of clearfil liner bond 2 and clearfil AP-X system on nonexposed and exposed primate teeth. Quint Int 729:177-88, 1998.
57. Tarim B, Hafez AA, Cox CF, Biocompatibility of Optibond and XR-bond adhesive systems in nonhuman primates. Int J Periodont Rest Dent 18:87-99, 1998.
58. Walton RE, Langeland K, Migration of materials in the dental pulp of monkeys. J Endod 4:167-77, 1978.
59. Gwinnett AJ, Cox CF, Discussions regarding the observation of, presence and persistence of Ca(OH)2 and resin particles in the dental pulp following direct pulp capping. Personal communication, Jan 1997.
60. Gwinnett AJ, Tay FR, Early and intermediate time response of the dental pulp to an acid etch technique in vivo. Am *J Dent* 10:35-44, 1998.
61. Mjor IA, Dahl E, Cox CF, Healing of pulp exposures: an ultrastructural study. J Oral Path Med 20:496-501, 1991.
62. Horsted P, El Attar K, Langeland K, Capping of monkey pulps with Dycal and a Ca-eugenol cement. Oral Surg Oral Med Oral Path 52:531-53, 1981.
63. Schröder U, Granath LE, On enamel dentin resorption in deciduous molars treated by pulpotomy and capped with calcium hydroxide. Odonto Revy 22:179-89, 1971.
64. Grossman LI, Root Canal Therapy, 1st ed. Philadelphia, Lea & Febiger, 1940, pp 135-58.
65. Grossman LI, Irrigation of root canals. *J Am Dent Assoc* 30:1915-7, 1943.
66. Sudo C, A study on partial pulp removal (pulpotomy) using NaOCl (sodium hypochlorite). Jpn J Stom Soc 26:1012-24, 1959.
67. Hirota K, A study on partial pulp removal (pulpotomy) using four different tissue systems. J Jpn Stom Soc 26:1588-603, 1959.
68. Katoh M, Kidokoro S, Kurosu K, A study on the amputation of pulp using sodium hypochlorite (NaOCl). Jpn J Pediat Dent 16:107-16, 1987.
69. Cox CF, Hafez AA, et al, Biocompatibility of nine primer, adhesive and resin composite systems on non-exposed and exposed pulps of non-human primates. Am *J Dent* 10:55-63, 1998.
70. Kitasako Y, Inokishi S, Tagami J, Effect of direct resin pulp capping techniques on short-term response of mechanically exposed pulps. *J Dent* 27:257-63, 1999.

Glass Ionomers in Contemporary Restorative Dentistry — A Clinical Update

Edmond R. Hewlett, DDS, and Graham J. Mount, BDS, DDSc

ABSTRACT Glass ionomers are applicable to many restorative situations, both as stand-alone restoratives and in conjunction with composite resins. This article reviews the clinically relevant properties of glass ionomers, the differences between them and composite resins, and their clinical applications. An understanding of these concepts is essential for the optimal incorporation of these materials into common restorative procedures.

AUTHORS

Edmond R. Hewlett, DDS, is an associate professor and vice chair of the Division of Restorative Dentistry at the University of California at Los Angeles.

Graham J. Mount, BDS, DDSc, is in general dental practice and is a visiting research fellow at the University of Adelaide, Australia.

The glass-ionomer family of restorative materials has evolved during the past 30 years into a diverse group of products that includes direct restoratives, luting agents, liners, and bases, as well as pit and fissure sealants, all available in both the conventional and resin-modified varieties (Table 1). Such a broad array of choices may pose a dilemma to the clinician with respect to selecting and utilizing these materials over their composite resin-based counterparts. Glass ionomers differ from composite resins on several fundamental levels, including composition (water-based vs. resin-based), setting reaction (acid-base reaction vs. resin polymerization), and nature of the tooth/restoration interface (chemical adhesion and ion exchange vs. micromechanical attachment to acid-demineralized enamel and dentin). These and other attributes of glass ionomers render them applicable to many restorative situations, both as stand-alone restoratives and in conjunction with composite resins. This article reviews the clinically relevant properties of glass ionomers, the aforementioned differences between them and composite resins, and their clinical applications. An understanding of these concepts is essential for the optimal incorporation of these materials into common restorative procedures.

Terminology

The use of the term "cement" in reference to glass ionomers can be confusing. "Cement" as it applies to restorative dentistry typically connotes a luting agent, i.e., an intermediary material that serves to bind two objects together.[1] The term has also been used in reference to liners and bases, temporary restoratives, and certain permanent direct restoratives (silicate and glass-ionomer).[2-4] A general definition explains this multiple usage, describing cement as "any substance which sets to a hard mass on being mixed with water or other medium."[4] A glass ionomer is thus appropriately referred to as a dental cement in the traditional

Table 1

A Representative Sampling of Glass-Ionomer Products

Material type	Conventional glass ionomers	Resin-modified glass ionomers
Luting agent	Fuji I[1] GlassIonomer CV-Plus[2] Ketac-Cem[3]	Fuji Plus[1] Fuji Cem[1] Rely-X Luting Cement[3]
Restorative/core buildup	Fuji II[1] GlassIonomer Cement Type II[2] Ketac Aplicap II[3]	Fui II LC[1] Fuji II LC Core[1] Vitremer Core Buildup/Restorative[3]
Liner/base	GlassIonomer Lining Cement[2] GlassIonomer Base Cement[2] Lining Cement[1] Ketac-Bond[3]	Fuji Lining LC[1] Vitrebond[3]
Silver/glass-ionomer cermet restorative	Ketac-Silver[3]	
Silver/glass-ionomer admixture restorative	Miracle Mix[1]	
High viscosity restorative	Fuji IX GP[1]/Fuji IX GP Fast[1] Ketac-Molar Aplicap[3]	
Pit/fissure sealant	Fuji Triage[1]	
Root canal sealer	Ketac Endo Aplicap[3]	
Composite bonding agent		Fuji Bond LC[1]

[1]GC America
[2]Shofu
[3]3M ESPE

sense and, like other cements, falls into several categories of clinical use. It is, however, the only dental cement currently represented in the permanent direct restorative category of available materials. The term “cement” is nonetheless not always necessary in common usage.

Conventional Glass Ionomers

The first glass-ionomer material was introduced by Wilson and Kent in 1972 as a “new translucent dental filling material” recommended for the restoration of cervical lesions.5 This original formulation was the product of efforts to develop a replacement for silicate cements, which had been used for decades in cervical restorations. The components of a glass ionomer are a powdered fluoroaluminosilicate glass similar to the one used in silicate cements and a polyalkenoic acid. The latter component is a complex polymeric blend of (primarily) acrylic, itaconic, and maleic acids chosen for their ability to form a cement when mixed with glass and effect ion-exchange adhesion to tooth structure.6 Depending on the product, the liquid component does not necessarily contain all of the acid. Polyacrylic acid is often incorporated into the powder in its dehydrated form, leaving the liquid to consist of water or an aqueous solution of tartaric acid.6 These various composition characteristics are reflected in the more accurate and scientific term for glass ionomers, namely “glass-polyalkenoate cements.”

Mixing of the glass-ionomer powder and liquid generates an acid-base setting reaction (Figures 1 and 2) commencing with partial dissolution of the surface of the glass particles by the acid. Positive ions (Ca^{2+} and Al^{3+}) released into solution act to crosslink the acid polymer chains, forming an increasingly rigid matrix as the crosslinked network becomes tighter and more complex. Fluoride ion (F^-) is also released from the glass particles, becoming available for both uptake by adjacent tooth structure and release from the matrix into saliva. Fluoride neither plays a role in the glass-ionomer setting reaction nor is it incorporated into the matrix structure. Glass ionomer is thus not weakened significantly by fluoride release.

Limitations of Glass Ionomers

Since the introduction of glass ionomers, numerous modifications have been made to the liquid and powder components to improve the handling and physical properties of the set material. As with all restorative materials, there are strict rules for the clinical handling and placement of glass ionomers. The powder-to-liquid ratio is specific for each application, and mixing techniques are demanding. Consequently, the use of capsulated materials is strongly recommended to guarantee routine success. The setting reaction is not unlike amalgam in that there is an initial “snap” set within three minutes for all glass-ionomers, but the chemical reaction continues thereafter for a prolonged period. There is a tendency in the earliest stages for the material to take up additional water, but later the main risk becomes water loss leading to dehydration and cracking.

Early water sorption causes swelling (hygroscopic expansion) of the immature material and dissolution of reactive components, while dehydration allows loss of some of the water critical for continuation of the setting reaction. Both situations result in disruption of the setting reaction and resultant nonmature cement with unacceptable properties such as crazing, cracking, and loss of translucency.7 These untoward occurrences can be prevented by sealing the restoration surface immediately after removing the matrix to maintain the water balance using a light-

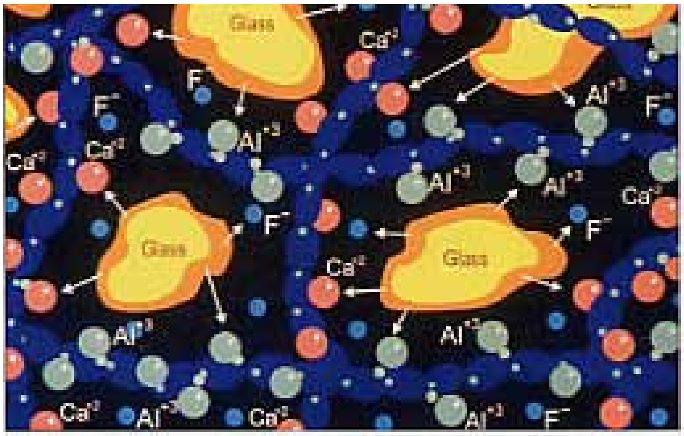


Figure 1. Theoretical diagram of the initial acid-base reaction between the glass powder and polyacid liquid components of glass ionomers. Note that only the surface of each particle is attacked by acid, releasing Ca, Al, and F ions (Reprinted with permission from An Atlas of Glass-Ionomer Cements: A Clinician's Guide, 3rd ed., Martin Dunitz Publishers, London, 2002).

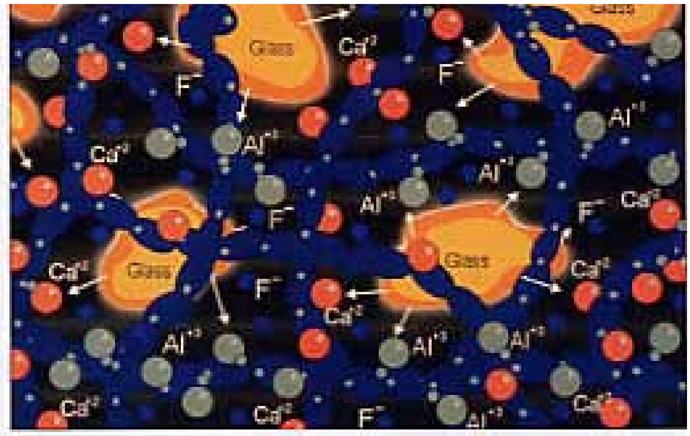


Figure 2. A fully set and mature glass ionomer is characterized by Ca and Al chains condensed onto the acidic polymer to form a rigid matrix surrounding the partially dissolved particles. F ions remain free and are not part of the matrix (Reprinted with permission from An Atlas of Glass-Ionomer Cements: A Clinician's Guide, 3rd ed., Martin Dunitz Publishers, London, 2002).

polymerized unfilled resin enamel bond.[8]

The problem of water balance maintenance was most pronounced with the original glass-ionomer restorative materials but has been largely overcome in recent times. In fact, for the modern high-viscosity autocure materials, loss of water through dehydration is the greatest problem; and its prevention in the oral environment is not difficult. It is nevertheless recommended that final polishing of glass-ionomer restorations be delayed for about 24 hours to allow further maturation of the material. Other properties such as compressive and flexural strength and fracture toughness will limit glass-ionomer use as a restorative material to areas not subject to occlusal stress unless well-supported by surrounding tooth structure. Wear resistance improves markedly as the restoration matures, and clinical results suggest that wear is not a problem.[9]

Advantages of Glass Ionomers

In spite of their limitations, glass-ionomer restoratives possess several compelling characteristics that merit their inclusion in the adhesive restorative armamentarium.

Ion Exchange

It must be noted that ion migration within or through any material can only occur in the presence of water. Since glass ionomer is water-based, it is not surprising that numerous studies have reported continuing release of fluoride from set glass ionomer over prolonged periods;[10-12] and higher levels of fluoride release from glass ionomers as compared to other fluoride-containing restorative materials.[13-15]

Additionally, uptake of fluoride by enamel and dentin walls adjacent to glass-ionomer restorations has been demonstrated in both in vitro[16-18] and in vivo[19,20] studies. The high levels of fluoride release observed in the days immediately following restoration placement reflect release of fluoride from the exposed glass particles at the outer surface of the restoration. Initial fluoride release levels also likely reflect dissolution of small amounts of the material mass from the surface during the minimally mature stage when solubility of the material is highest. Furthermore, a recent study also implicates early permeability of some glass ionomers as an explanation for high initial fluoride levels.[21] Resin-modified glass ionomers exhibited significantly higher levels of initial fluoride release than their less permeable conventional counterparts. Fluoride release levels drop after the first week and stabilize after two to three months, with continued release at these lower levels for many years.[22] This phenomenon reflects slow fluoride release from the glass particles and slower diffusion of released fluoride from deeper areas of the matrix. It is generally accepted that both the short- and long-term levels of fluoride release are nonetheless adequate to inhibit demineralization in adjacent tooth structure[17,20,23-27] and to increase the fluoride concentration in saliva.[28,29] Fluoride release levels have also been shown to temporarily rise following exposure of glass-ionomer restorations to topical fluoride preparations[21,30-32] suggesting a "rechargeable" quality to the fluoride release and giving further credence to the notion of glass ionomer's inherent anticariogenic properties. The aforementioned higher permeability of resin-modified glass ionomers likely accounts for the higher recharge potential of these materials as compared with the conventional types.[21]

There is gathering evidence that caries inhibition by glass ionomers not only is a question of fluoride release but

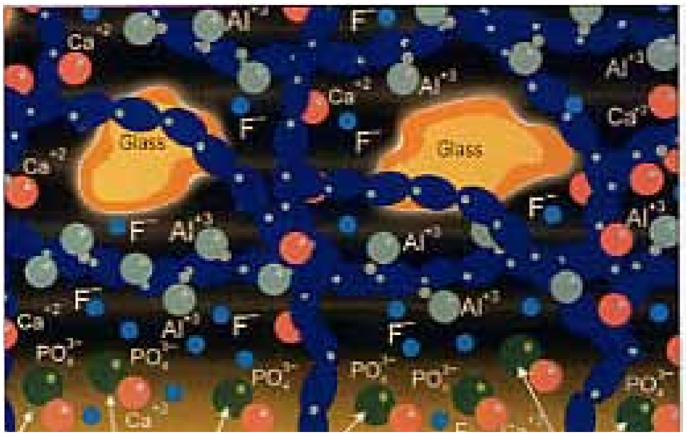


Figure 3. A theoretical diagram showing ion exchange adhesion between a glass ionomer and tooth structure. Polyacid chains penetrate enamel and dentin surfaces displacing phosphate and calcium ions, ultimately producing an ion-enriched layer at the glass-ionomer/tooth interface (Reprinted with permission from An Atlas of Glass-Ionomer Cements: A Clinician's Guide, 3rd ed., Martin Dunitz Publishers, London, 2002).

Figure 4. Detail of a glass-ionomer restoration placed in vitro showing the ion exchange layer between enamel and dentin. The specimen was lightly etched to remove the smear layer. The ion-exchange layer is more acid-resistant than both the glass ionomer and the enamel. Original magnification 10,000x (Reprinted with permission from An Atlas of Glass-Ionomer Cements: A Clinician's Guide, 3rd ed., Martin Dunitz Publishers, London, 2002).

also involves a continuing ion exchange among the restoration, the surrounding tooth structure, and the saliva. It has been shown that the steady improvement in wear resistance results from movement of fluoride ions out of the restoration surface followed by the uptake of calcium and phosphate ions from the saliva to maintain the electrolytic balance in the restoration.[33] There is further evidence of the transfer of calcium, phosphate, and strontium ions from the glass-ionomer restoration deep into demineralized dentin and surrounding enamel.[34] This remineralization capability renders glass ionomer particularly useful as a long-term provisional restoration in the presence of a high-caries risk inasmuch as it will help to heal damaged tooth structure.

These properties of glass ionomers give rise to a variety of clinical indications not enjoyed by other restorative materials. Of course, no material can be regarded as a prevention or cure for caries. Once the etiologic factors for caries have been eliminated or controlled, however, glass ionomer is most valuable in assisting the healing of remaining tooth structure that has been demineralized and damaged.

Adhesion to Tooth Structure

Unlike adhesive resins, which bond micromechanically to partially demineralized enamel and dentin, glass ionomers bond chemically to mineralized tooth structure through an ion exchange mechanism[35] (Figures 3 and 4). The cavity surface must first be conditioned by applying a 10 percent solution of polyacrylic acid for 10 seconds. A thorough wash of the cavity with air/water spray then removes the smear layer and enhances the wettability of the cavity surface.[36-38] In contrast to the aggressive demineralization produced with phosphoric acid, the action of this milder conditioning is largely limited to smear layer removal[5] (Figures 5 and 6). Mineral content of the underlying tooth surface will remain relatively intact, and there will be a more consistent and predictable substrate for bonding. Following conditioning and rinsing, cavity surfaces should be dried but not dessicated[5]. Insofar as a mineralized tooth substrate is essential for chemical bonding with glass ionomers, and as these cements are unable to infiltrate and "hybridize" the exposed collagen fibers of acid-etched dentin, conditioning with phosphoric acid prior to glass-ionomer placement is strictly contraindicated.

Ion exchange adhesion between tooth structure and the restoration develops because, in the presence of the polyalkenoic acid in the freshly mixed cement, ions are released from both the glass particles (calcium and aluminum) and the tooth structure (calcium and phosphate). These released ions serve to buffer the acid, effect the initiation of setting, and produce an ion-enriched interfacial layer firmly attached to both the restoration and the tooth. Once the material has matured, any failure will be cohesive within the glass ionomer (the weaker material), leaving behind the ion-enriched layer bonded to the dentin and enamel at the restoration/tooth interface. One investigator has reported findings suggesting some degree of chemical adhesion to the collagen fibers.[39] If the glass ionomer is properly placed, microleakage between the restoration and the cavity walls will be decreased. This in turn ensures absence of post-insertion sensitivity when glass ionomer is used as a base under composite resin.[40,41]

Glass-ionomer restoratives undergo a small setting shrinkage; but, providing the water balance is maintained, the slow progression of the setting reaction combined with water uptake from the oral environment will counteract

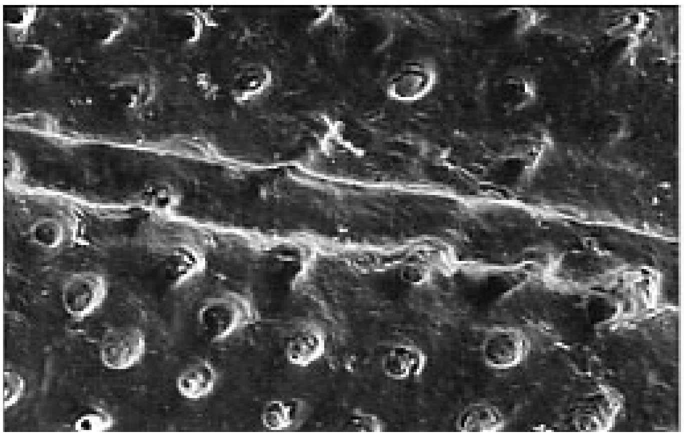


Figure 5. Scanning electron micrograph showing dentin conditioned with 10 percent polyacrylic acid for 10 to 15 seconds. Many of the dentin tubules remain occluded, but the surface is relatively clean. Original magnification 800x (Reprinted with permission from An Atlas of Glass-Ionomer Cements: A Clinician's Guide, 3rd ed., Martin Dunitz Publishers, London, 2002).

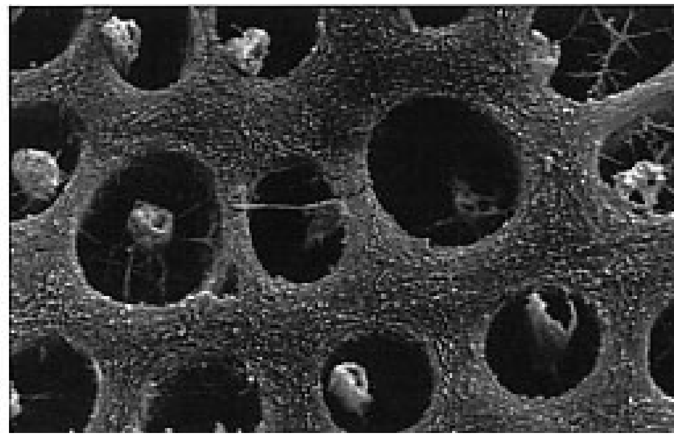


Figure 6. This scanning electron micrograph should be compared with Figure 5. The cavity has been etched with 37 percent orthophosphoric acid for 15 seconds and shows the demineralization of the collagen rendering it unsuitable for ion-exchange adhesion. Original magnification 12,000x.

the volumetric change and minimize shrinkage-induced stresses at the restoration/tooth interface.42 They also exhibit a low coefficient of thermal expansion that is similar to that of tooth structure.

Resin-Modified Glass Ionomers

Historically, the first significant modification to glass ionomers came through the addition of small quantities of light-polymerizable resin groups. This has proven to be a successful strategy for simplifying the water balance maintenance while preserving favorable characteristics and improving physical properties and translucency of glass ionomer. The resultant materials have been identified by several terms, including "resin ionomers" and "hybrid ionomers," but "resin-modified glass ionomer" is most commonly used to differentiate these materials from those that set solely by acid-base reaction, i.e., the conventional autocure glass ionomers.

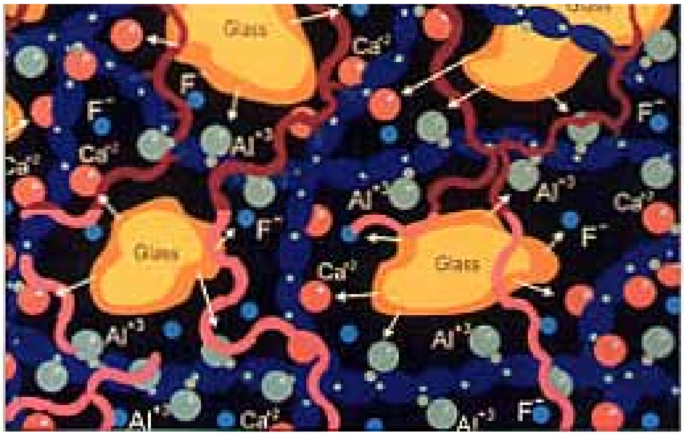
"Resin-modified" specifically refers to the addition of polymerizable resin groups (usually 2-hydroxyethylmethacrylate, or HEMA) by grafting them to molecules of the acidic liquid component. The result is a complex liquid that maintains acid reactivity independent of the newly acquired ability to be light polymerized. It is important to recognize that the traditional acid/base setting reaction of the autocure glass ionomer is still present and will continue as normal.66 Only about 5 percent of the mixed cement will be resin, and when polymerized it will impart strength as well as protection to the ongoing acid-base reaction from dehydration and water sorption (Figures 7 and 8). Resin-modified glass ionomers are thus occasionally referred to as "dual-cure" in reference to these two distinct setting modes. Some manufacturers additionally include a chemical initiator for the HEMA that, along with the usual photoinitiated and acid-base reactions, gives rise to the "tricure" terminology (Figure 8).

Originally marketed in the form of cavity liners, resin-modified glass-ionomer product lines expanded to include restoratives and luting agents. All of these materials retain the most desirable qualities of conventional versions, namely fluoride release,43 ion exchange adhesion to conditioned enamel and dentin,44 and low interfacial shrinkage stress.41 The enhancements over conventional types, particularly in the case of restoratives, include significantly improved resistance to microleakge,45 on-command hardening and immediate finishing as with composite resins,20,46 improved mechanical properties and translucency,44 and reduced water sensitivity.44 Despite the transient resistance to water movement in and out of the restoration, post-finishing sealing of a resin-modified glass-ionomer restoration with light-polymerized unfilled resin is recommended to protect acid-base reactive components at the restoration's outer surface.20,46 Recent studies additionally suggest that delayed finishing/polishing of these materials may improve resistance to microleakage.47

High Viscosity Autocure Glass Ionomers

Other attempts at improving glass-ionomer properties have involved metal reinforcement (addition of amalgam alloy powder) as well as sintering of silver particles to the glass component to form a cermet (ceramic-metal). Data on improvements in physical properties48-51 and clinical performance,52,53 however, is equivocal; while other reports suggest diminished caries resistance compared to conventional glass ionomer restoratives.54,55

More recently, high-viscosity, high-strength versions of conventional autocure glass-ionomer restoratives have been introduced. Originally aimed at remote



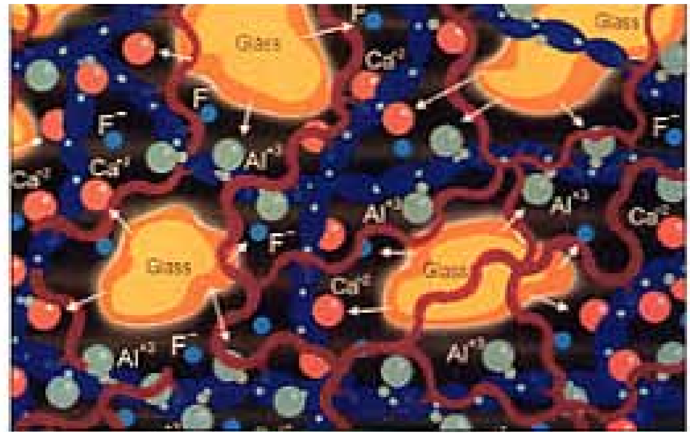


Figure 7. A theoretical diagram showing the influence of the resin in a resin-modified glass ionomer. The resins are light-activated to penetration depth of the curing light, providing protection for the ongoing acid-base reaction from immediate water uptake/loss. Red chains represent fully polymerized resins to the depth of penetration of the curing light (Reprinted with permission from An Atlas of Glass-Ionomer Cements: A Clinician's Guide, 3rd ed., Martin Dunitz Publishers, London, 2002).

Figure 8. Progress of the reaction shown in Figure 7. Chemical initiators allow polymerization of resin chains that were not activated via photo polymerization. Resin polymerization is now complete, and the autocure (acid-base) component has matured to the same degree as that of conventional glass ionomers (Figure 2) (Reprinted with permission from An Atlas of Glass-Ionomer Cements: A Clinician's Guide, 3rd ed., Martin Dunitz Publishers, London, 2002).

or underdeveloped regions lacking access to dental care,[56] these materials also have many applications in the traditional restorative setting. Improved physical properties result from chemical modifications and alterations to the heat history of the glass powder that allow higher powder-liquid ratios than earlier conventional restoratives. Characteristics include the adhesion and ion exchange common to all glass ionomers as well as fast setting times, and high levels of compressive and tensile strength, surface hardness, and fluoride release.[57] These attributes render these materials an excellent choice for bases, emergency temporary restorations, long-term provisional restorations, and final restorations in nonstress-bearing areas, particularly in high-caries-risk patients.[58,59] Contouring and finishing can begin five minutes after placement, using water spray to prevent dehydration, followed by surface sealing with resin to protect the continuing acid-base reaction.

Polyacid-Modified Composite Resins (Compomers)

"Compomers," originally introduced in Europe, have been available since 1993. The term "compomer" is an acronym derived from "composite" and "glass-ionomer," and it reflects the intent to produce a restorative that combines components and properties of both materials. Specifically, compomers purportedly possess the esthetic attributes of composite resins along with the fluoride-release advantage of glass ionomers.[60] Unlike true glass ionomers, however, compomers are resin-based materials containing no water; and the setting/polymerization of compomer restoratives involves neither mixing nor an acid-base reaction. Compomers are in fact light-polymerized composite resin restoratives, modified to contain ion-leachable glass particles and anhydrous (freeze-dried) polyalkenoic acid. The term "polyacid-modified composite resins" was thus proposed by McLean and colleagues[61] and is used commonly in the scientific literature to distinguish these materials from glass ionomers.

In the absence of water, the compomer composition prevents the aforementioned glass particles and anhydrous acid from reacting.[62] Eventual water uptake in the oral environment, however, initiates an acid-base reaction between these components with resultant diffusion of low levels of fluoride ion from the restoration.[62] Numerous in vitro studies have shown these fluoride release levels to be significantly lower than those measured for conventional and resin-modified glass-ionomers.[63-65] One recent study,[66] however, demonstrated equivalent rates of fluoride release for compomers and glass ionomers after three years. This finding, though, does not take into account the higher fluoride recharge/re-release capacity of glass ionomers compared with compomers.[21,29] The resin bonding agents required for compomer-tooth adhesion act as barriers to fluoride uptake from compomers into cavity walls and margins.

Mechanical properties of compomers tend to be somewhat inferior to those of conventional composite resins, thus limiting their use to areas subjected to low stresses.[62,67,68] Specifically, compomers (and microfill composite resins) are often recommended for restoration of non-carious cervical lesions as their flexibility (relative to hybrid composite resins) presumably renders them more resistant to detachment during tooth flexure.[69]

Clinical Applications for Glass-Ionomer Restoratives

Resin-modified and highly viscous ver-

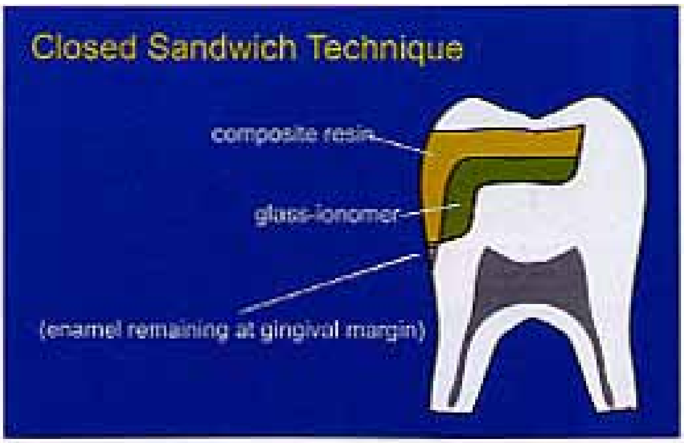


Figure 9. Closed sandwich technique. Missing dentin in a Class II cavity is replaced with either a resin-modified or high-viscosity glass ionomer. Composite resin is used to replace enamel and seal the enamel margins surrounding the cavity (Adapted from Ferrari77).

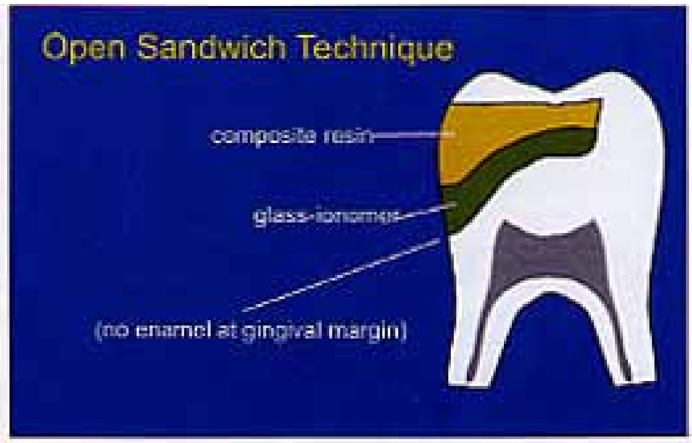


Figure 10. Open sandwich technique. This modification of the closed sandwich is utilized in Class II cavities lacking enamel at the cervical margin. A glass ionomer is used in lieu of composite resin to restore the cervical aspect of the proximal box, imparting optimal resistance to microleakage and secondary caries along dentin margins (Adapted from Ferrari77).

sions of glass-ionomer restorative materials can be used alone or in combination with composite resins to effectively treat many common restorative situations.

Sandwich Technique

The term "sandwich technique"20 refers to a laminated restoration using glass ionomer to replace dentin and composite resin to replace enamel. This strategy combines the most favorable attributes of the two materials, i.e., caries resistance,17,20-25 chemical adhesion to dentin,44 fluoride release43 and remineralization,33 and lower interfacial shrinkage stress41,70 of glass ionomer with the enamel bonding, surface finish, durability, and esthetic superiority of composite resin. Additionally, composite resin bonds micromechanically to set glass ionomers and chemically to the HEMA in resin-modified versions. Either resin-modified or highly viscous glass ionomers may be used, depending upon anticipated mechanical stresses and esthetic considerations.

The sandwich technique is applicable to Class II lesions in particular using either the "open" or "closed" variations (Figures 8 and 9). The open sandwich is specifically useful for deep Class II proximal box forms where the cervical margin lacks enamel. Numerous in vitro studies have reported improved resistance to microleakage and caries with this technique as opposed to resin bonding at dentin margins.71-75 Additionally, replacement of dentin in either the open or closed technique with glass ionomer minimizes the complexity of incremental build-up with composite resin. It will also eliminate acid etching of dentin and thus has potential to reduce or eliminate postoperative sensitivity caused by incomplete sealing of etched dentin.

Class III and Class V Lesions

Simple one-surface restorations that are not under occlusal load can be successfully restored with a glass ionomer alone, generally without lamination. The original autocure materials are very suitable, producing satisfactory esthetic results provided that water balance is maintained at insertion.76

Fissure Sealing

Long-term success with fissure sealing has been demonstrated using normal restorative glass ionomers. Proper conditioning prior to placement will ensure the ion exchange adhesion, and maturation over time allows acceptable longevity. The modern high-viscosity glass ionomers are now the preferred materials, and these can be placed under finger pressure to adapt the cement into the depths of the fissure.20

Root Caries

Glass ionomer, given its aforementioned attributes, is clearly the material of choice for root caries restorations. In particular, excellent ion exchange adhesion to dentin, caries inhibition, and simplified placement protocol as compared with composite resin render glass ionomer ideally suited to these situations. Relative esthetic limitations of glass ionomer tend to be inconsequential in root caries sites, and longevity of glass-ionomer restorations in these sites is excellent.8

High Caries Risk

High-viscosity glass-ionomer restoratives lend themselves well to short- and long-term management of patients at high risk for developing caries. In addition to sealing ability and ion exchange, these materials have abrasion resistance adequate for provisional restoration of occlusal and proximal surfaces. Frequent fluoride recharge of such restorations will likely occur via the topical fluoride regimens typically prescribed for such patients, and calcium and phosphate ions are constantly available from the saliva. There is a glass ionomer designed as a lining for high-caries-risk patients that exhibits a very high fluoride release, making it useful when demineralized dentin is to be left on the cavity floor.

Emergency Temporary Restorations

Fractured cusps/restorations can be quickly and predictably stabilized with glass ionomers pending definitive restoration. Adhesion properties of glass ionomer impart adequate retention even if mechanical undercuts are absent. Coverage of exposed dentin and sharp margins to provide enduring patient comfort is accomplished with minimal chair time.

Summary

Glass ionomers have evolved to become more user-friendly while retaining unique characteristics applicable to many contemporary restorative situations. An overview of glass ionomers is presented in an effort to acquaint the clinician with the material's attributes and utilization.

References

1. Academy of Prosthodontics, Glossary of prosthodontic terms, 7th ed. J Prosthet Dent 81:39-110, 1999.
2. Jablonski S, Jablonski's Dictionary of Dentistry. Krieger, Malabar, Fla, 1992, pp 158-9.
3. Zwemer TJ, Boucher's Clinical Dental Terminology, 4th ed. Mosby-Year Book, St. Louis, 1993, p 50.
4. Harty FJ, Concise Illustrated Dental Dictionary, 2nd ed. Wright/Butterworth-Heinemann Ltd, Oxford, 1994, p 47.
5. Wilson AD, Kent BE, A new translucent cement for dentistry. The glass-ionomer cement. Br Dent J 132(2):133-5, 1972.
6. Mount GJ, An Atlas of Glass-ionomer Cement: A Clinician's Guide, 3rd ed. Martin Dunitz, London, 2002.
7. Anusavice KJ, Dental cements for restoration and pulp protection in Phillips' Science of Dental Materials, 10th ed. WB Saunders Co, Philadelphia, 1996.
8. Earl MSA, Mount GJ, Hume WR, The effect of varnishes and other surface treatments on water movement across the surface of a glass-ionomer cement: II. Austral Dent J 1989, 34:326-9.
9. Mount GJ, Longevity in glass-ionomer restorations: review of a successful technique. Quintessence Int 28:643-50, 1997.
10. Wilson AD, Groffman DM, Kuhn AT, The release of fluoride and other chemical species from a glass-ionomer cement. Biomaterials 6:431-3, 1985.
11. Swartz MC, Phillips RW, Clark HE, Long-term fluoride release from glass-ionomer cements. *J Dent* Res 63:158-60, 1984.
12. Forsten L, Short- and long-term fluoride release from glass ionomers and other fluoride-containing filling materials in vitro. Scand *J Dent* Res 98:179-85, 1990.
13. Yap AU, Tham SY, et al, Short-term fluoride release from various aesthetic restorative materials. Oper Dent 27(3):259-65, 2002.
14. Asmussen E, Peutzfeldt A, Long-term fluoride release from a glass-ionomer cement, a compomer, and from experimental resin composites. Acta Odontol Scand 60(2):93-7, 2002.
15. Muller U, Kielbassa AM, et al, Fluoride release from light-curing restorative materials. Am *J Dent* 13(6):301-4, 2000.
16. Wesenberg G, Halls E, The in vitro effect of a glass-ionomer cement on dentine and enamel walls. J Oral Rehabil 7:35-42, 1980.
17. Tsanidis V, Koulourides T, An in vitro model for assessment of fluoride uptake from glass-ionomer cements by dentin and its effect on acid resistance. *J Dent* Res 71:7-12, 1992.
18. Tam LE, Chan GP, Yim D, In vitro caries inhibition effects by conventional and resin-modified glass-ionomer restorations. Oper Dent 22:4-14, 1997.
19. Skarveit L, Tveit AB, et al, In vivo fluoride uptake in enamel and dentin from fluoride containing materials. *J Dent* Child 57:97-100, 1990.
20. Shimokobe H, Komatsu H, Matsui J, Fluoride content in human enamel after removal of the applied cement. *J Dent* Res 66(special issue):131 (abstract 96), 1982.
21. Preston AJ, Agalamanyi EA, et al, The recharge of esthetic dental restorative materials with fluoride in vitro-two years' results. Dent Mater 19(1):32-7, 2003.
22. Mount GJ and Bryant RW, Glass-ionomer materials. In, Mount GJ, Hume WR, eds, Preservation and Restoration of Tooth Structure. Mosby International Ltd, London, 1998.
23. Torii Y, Itota T, et al, Inhibition of artificial secondary caries in root by fluoride-releasing restorative materials. Oper Dent 26(1):36-43, 2001.
24. Donly KJ, Segura A, et al, Clinical performance and caries inhibition of resin-modified glass-ionomer cement and amalgam restorations. *J Am Dent Assoc* 130(10):1459-66, 1999.
25. Donly KJ, Grandgenett C, Dentin demineralization inhibition at restoration margins of Vitremer, Dyract and Compoglass. Am *J Dent* 11(5):245-8, 1998.
26. Pereira PN, Inokoshi S, et al, Microhardness of in vitro caries inhibition zone adjacent to conventional and resin-modified glass-ionomer cements. Dent Mater 14(3):179-85, 1998.
27. Randall RC, Wilson NH, Glass-ionomer restoratives: a systematic review of a secondary caries treatment effect. *J Dent* Res 78(2):628-37, 1999.
28. Koch G, Hatibovic-Kofman S, Glass-ionomer cements as a fluoride release system in vivo. Scand *J Dent* Res 14:267-73, 1990.
29. Hattab FN, el Mowafy OM, et al, An in vivo study on the release of fluoride from glass-ionomer cement. Quintessence Int 22:221-4, 1991.
30. Forsten L, Fluoride release and uptake by glass-ionomers. Scand *J Dent* Res 99:241-5, 1991.
31. Attar N, Onen A, Fluoride release and uptake characteristics of aesthetic restorative materials. J Oral Rehabil 29(8):791-8, 2002.
32. Itota T, Okamoto M, et al, Release and recharge of fluoride by restorative materials. Dent Mater 18(4):347-53, 1999.
33. Nicholson JW, Czarnecka B, Limanowska-Shaw H, Effect of glass-ionomer and related dental cements on the pH of lactic acid storage solutions. Biomaterials 20:155-8, 1999.
34. Ngo H, Marino V, Mount GJ, Calcium, strontium, aluminum, sodium and fluoride release from four glass ionomers. *J Dent* Res 77:641(Abstr 75), 1998.
35. Mount GJ, Adhesion of glass-ionomer cement in the clinical environment. Oper Dent 16: 141-8, 1991.
36. Ngo H, Mount GJ, Peters MCRB, A study of glass-ionomer cement and its interface with the enamel and dentin using a low-temperature, high-resolution scanning electron microscope technique. Quintessence Int 28:63-9, 1997.
37. Powis DR, Folleras T, et al, Improved adhesion of a glass-ionomer cement to dentin and enamel. *J Dent* Res 61:1416-22, 1982.
38. Hewlett ER, Caputo AA, Wrobel DC, Glass-ionomer bond strength and treatment of dentin with polyacrylic acid. J Prosth Dent 66(6):767-72, 1991.
39. Akinmade A, Adhesion of glass-polyalkenoate cement to collagen. *J Dent* Res Special issue:181(Abstr 633), 1994.
40. Christensen GJ, Preventing postoperative tooth sensitivity in class I, II and V restorations. *J Am Dent Assoc* 133(2):229-31, 2002.
41. McLean JW, Dentinal bonding agents versus glass-ionomer cements. Quintessence Int 25: 659-67, 1996.
42. de Gee AJ, Physical properties of glass-ionomer cement: setting shrinkage and wear. In, Davidson CL, Mjor IA, eds, Advances in Glass-Ionomer Cements. Quintessence Publishing, Chicago, 1999.
43. Momoi Y, McCabe JF, Fluoride release from light-activated glass-ionomer restorative cements. Dent Mater 9:151-4, 1993.
44. Saito S, Tosaki S, Hirota K, Characteristics of glass-ionomer cements. In, Davidson CL, Mjor IA, eds, Advances in Glass-Ionomer Cements. Quintessence Publishing, Chicago, 1999.
45. Martin FE, O'Rourke M, Marginal seal of cervical tooth-coloured restorations. A laboratory investigation of placement techniques. Austral Dent J 38:102, 1993.
46. Chuang SF, Jin YT, et al, Effect of various surface protections on the margin microleakage of resin-modified glass-ionomer cements. J Prosthet Dent 86(3):309-14, 2001.
47. Yap AUJ, Yap Wy, et al, Effects of finishing/polishing techniques on microleakage of resin-modified glass-ionomer cement restorations. Oper Dent 28:36-41, 2003.
48. Tjan AH, Morgan DL, Metal reinforced glass ionomers: their flexural and bond strengths to tooth substrate. J Prosthet Dent 59:137-41, 1988.
49. Beyls HMF, Verbeek RMH, et al, Compressive strength of some polyalkenoates with or without dental amalgam alloy incorporation. Dent Mater 7:151-4, 1991.
50. Kerby RE, Bleiholder RF, Physical properties of stainless steel and silver-reinforced glass-ionomer cements. *J Dent* Res 70:1358-61, 1991.
51. Williams JA, Billington RW, Increase in compressive strength of glass-ionomer cements with respect to time periods of 24 hours to four months. J Oral Rehabil 18:163-8, 1991.
52. Kramer N, Frankenberger R, Clinical performance of a condensable metal-reinforced glass-ionomer cement in primary molars. Br Dent J 190(6):317-21, 2001.
53. Yap AU, Teo JC, Teoh SH, Comparative wear resistance of reinforced glass-ionomer restorative materials. Oper Dent 26(4):343-8, 2001.
54. Dionysopoulos P, Kotsanos N, et al, Artificial caries formation around fluoride-releasing restorations in roots. J Oral Rehabil 25(11):814-20, 1998.
55. Herrera M, Castillo A, et al, Antibacterial activity of glass-ionomer restorative cements exposed to cavity-producing microorganisms. Oper Dent 24(5):286-91, 1999.
56. Frecken JE, Pilot T, et al, Atraumatic Restorative Treatment (ART): rationale, technique and development. J Public Health Dent 56:135-40; discussion 161-3, 1996.
57. Yap AU, Pek YS, Cheang P, Physico-mechanical properties of a fast-set highly viscous GIC restorative. J Oral Rehabil 30(1):1-8, 2003.
58. Smales RJ, Gao W, In vitro caries inhibition at the enamel margins of glass-ionomer restoratives developed for the ART

technique. *J Dent* 28:249-56, 2000.
59. Hu JY, Li YQ, et al, Restoration of teeth with more-viscous glass-ionomer cements following radiation-induced caries. Int Dent J 52(6):445-8, 2002.
60. Mount GJ, Glass-ionomers: Advantages, disadvantages, and future implications. In Davidson CL, Mjor IA, eds, Advances in Glass-Ionomer Cements. Quintessence Publishing, Chicago, 1999.
61. McLean JW, Nicholson JW, Wilson AD, Proposed nomenclature for glass-ionomer dental cements and related materials. Quintessence Int 25:587-9, 1994.
62. Cattani-Lorente MA, Dupuis V, et al, Comparative study of the physical properties of a polyacid-modified composite resin and a resin-modified glass-ionomer cement. Dent Mater 15(1):21-32, 1999.
63. Helvatjoglu-Antoniades M, Karantakis P, et al, Fluoride release from restorative materials and a luting cement. J Prosthet Dent 86(2):156-64, 2001.
64. Yip HK, Smales RJ, Fluoride release from a polyacid-modified resin composite and 3 resin-modified glass-ionomer materials. Quintessence Int 31(4):261-6, 2000.
65. Karantakis P, Helvatjoglou-Antoniades M, et al, Fluoride release from three glass ionomers, a compomer, and a composite resin in water, artificial saliva, and lactic acid. Oper Dent 25(1):20-5, 2000.
66. Asmussen E, Peutzfeldt A, Long-term fluoride release from a glass-ionomer cement, a compomer, and from experimental resin composites. Acta Odontol Scand 60(2):93-7, 2002.
67. Gladys S, Van Meerbeek B, et al, Comparative physico-mechanical characterization of new hybrid restorative materials with conventional glass-ionomer and resin composite restorative materials. *J Dent* Res 76(4):883-94, 1997.
68. Meyer JM, Cattani-Lorente MA, Dupuis V, Compomers: between glass-ionomer cements and composites. Biomaterials 19(6):529-39, 1998.
69. Starr CB, Class V Restorations. In, Summitt JB, Robbins JW, et al, eds, Fundamentals of Operative Dentistry -- a Contemporary Approach, 2nd ed. Quintessence Publishing, Chicago, 2001.
70. Dauvillier BS, Feilzer AJ, et al, Visco-elastic parameters of dental restorative materials during setting. *J Dent* Res 79(3):818-23, 2000.
71. Hagge MS, Lindemuth JS, et al, Effect of four intermediate layer treatments on microleakage of Class II composite restorations. Gen Dent Sep-Oct;49(5):489-95, 2001.
72. Loguercio AD, Alessandra R, et al, Microleakage in class II composite resin restorations: total bonding and open sandwich technique. J Adhes Dent 4(2):137-44, 2002.
73. Wibowo G, Stockton L, Microleakage of Class II composite restorations. Am *J Dent* 14(3):177-85, 2001.
74. Dietrich T, Losche AC, et al, Marginal adaptation of direct composite and sandwich restorations in Class II cavities with cervical margins in dentine. *J Dent* Feb;27(2):119-28, 1999 (erratum in: *J Dent* 27(6):463-4, 1999).
75. Gladys S, Van Meerbeek B, et al, Microleakage of adhesive restorative materials. Am *J Dent* 14(3):170-6, 2001.
76. Mount GJ, Clinical performance of glass ionomers. Biomaterials 19:573-9, 1998.
77. Ferrari M, Use of glass ionomers as bondings, linings, or bases. In, Davidson CL, Mjor IA, eds, Advances in Glass-Ionomer Cements. Quintessence Publishing, Chicago, 1999.

To request a printed copy of this article, please contact/ Edmond R. Hewlett, DDS, UCLA School of Dentistry, Box 951668, Los Angeles, CA 90095-1668.

New and Improved

Robert E. Horseman, DDS

In the beginning, there was red compound. It was widely used by dentists of the day, not because of its uncanny ability to raise enormous blisters on skin and mucosa, nor its tendency to become a permanent fixture on any article of clothing it contacted, but because there wasn't anything else.

In a small laboratory on the outskirts of Peoria, Ill., amateur chemist and part-time tarot card reader Farley Krautzmeyer accidentally calcined some gypsum and ended up with slightly hydrated calcium sulfate. He called it "plaster of Peoria" in honor of his mother, Margie, and tried to flog it as a cure for hemorrhagic fever. It was not until he was persuaded to change the name to a classier sounding "plaster of Paris" did it find a ready outlet to the dental profession, strengthening the widely held belief that you could sell dentists anything.

Scores of old-time dentists who are now deceased or seriously deranged were brought up on red compound and plaster of Paris before they graduated to alginates, hydrocolloids and polyvinylsiloxanes. They have always had to take a lot on faith. When dentists were told that alginates were made out of seaweed, nobody questioned the patent absurdity of that any more than they doubted that polyvinylsiloxane was a real word.

Modern technology has far exceeded the ability of the average practitioner to grasp the scope and limitations of the materials he is offered. The profession is at the mercy of people who have nothing to do with dentistry except to exploit the gullibility of its members.

Dentists make this exploitation easy because basic to the soul of every one of them is the belief that there has always got to be a better way of doing things -- a superior material, a slicker machine or instrument, or, when you get right down to it, a better way of making a living.

So when a company tells us it has a better product than the one we are currently using, we can't dump the old issue fast enough.

The brand loyalty that manufacturers are so anxious to build isn't any more substantial than a patient's vow to floss daily. Some manufacturers understand this fickleness very well and play up to it by releasing a "new" product every few weeks that either supplements or displaces last month's offering.

Where they go wrong is offering the new product with a 30-day free trial period or promising to cheerfully refund the purchase price if you mail back the unused portion to them. If they would check more carefully, they would find that sort of generosity unnecessary.

Every dentist has shelves of stuff that he will never get around to returning. By the time he finds the original invoice, tries to imagine what he did with the box the stuff came in, and then contemplates dealing with UPS or FedEx or, worse yet, standing in line at the post office, the incentive to get his money back has evaporated.

The rate at which new materials are offered leaves him little time to reflect on his inability to understand the ones he already has. So the dentist tucks the material away, promising himself to use it some time in the future that, of course, never comes.

The point is that we should all be more cognizant vis-à-vis the way we are being manipulated. Once we understand that, we can have more discretionary income and more cupboard space for the denture adhesives that come every month.

We picture the process something like this:

The executives of Big Dental Manufacturing Co. are sitting around the boardroom table brainstorming ideas for increasing their pensions and perhaps choosing a venue for the company picnic.

Chairman: Any ideas? Anybody?

Chemist: As you know, we haven't introduced a new product for two weeks. Our new thrixotopic, hydrophobic ENAM-ELASTIC cross-linked monomer with the controlled durometer for easy mouth removal is doing well on the market, but showing early signs of faltering toward the end of the month.

Advertising: He's right. Company espionage reports that SUPERIOR SILICONES is introducing its biocompatible, nontoxic, self-limiting bite relaxer this week. It could be a tough week product-wise.

Chemist: What if we shift the benzene ring counter-clockwise two points, add a microminum of Yellow #2 to ENAM-ELASTIC, and push it as a state-of-the-art breakthrough in cosmetic bonding?

Chairman: Not bad, Charlie. It could fly, but will it have legs? What do you say, Art?

Advertising: Well, it worked in April, but Lorelei here has a better scam, I think.

Marketing: I say we go to three eight-hour shifts, change the packaging to predominately periwinkle blue and product color to a contrasting cerise. If Charlie can give us a viscosity change of 0.2 either up or down, we can market it as the most advanced, reinforced -- ah, what is this stuff anyway?

Chairman: It doesn't matter. If we can beat SUPERIOR's deadline by 24 hours, we can get hot on the introduction of our light-cured prophy paste.

And that, friends, is how you come to have packages of 50 variations on a theme on your shelves. Maybe with a little bit of luck, we'll come full circle and only have to choose between red or black compound again. Of course, it will come in 10 different kinds of packages.