CDA

Materials Selection

Luting Agents

Resins and Porcelain

JOURNAL OF THE CALIFORNIA DENTAL ASSOCIATION VOL.34 NO.2

February 2006

DENTAL MATERIALS

SAJID A. JIVRAJ, DDS, MSEd,
and TERRY E. DONOVAN, DDS

OF THE CALIFORNIA DENTAL ASSOCIATION
Journal
CDA Journal
Volume 34, Number 2
FEBRUARY 2006

DEPARTMENTS

FEATURES

One Smile at a Time

Tonight I had the responsibility of putting my son to bed. He is almost 2. Part of the nightly routine is brushing his teeth. He will grab the toothbrush with great exuberance and put it in his mouth. He even hums to simulate the sound of my electric brush. But, alas, when it comes to plaque removal and cavity prevention, his brushing is all but ineffective. Dr. Nouryani, his dentist, advised my wife and me that we must "get in there" and brush for him to be effective. And so the nightly struggle ensues. "After two or three weeks," Dr. Nouryani said, "he will let you brush his teeth without struggling. He'll get used to it, and even learn to like it." That was four months ago. He has become twice as big, twice as strong, and thus, four times more resistant. It's a two-person job. Tonight, when I was forced to go it alone, I succumbed to his formidable defense. This brushing would have earned a C-minus grade by our professional standards. I retreated to the cushion in the corner where the evening progressed to story time and then, by God's grace, "night-night."

In spite of this rough night, I know my son is fortunate and so am I. We have many blessings. I have a wife and partner with whom I share all responsibilities of raising a child. We have the means to care for our son, have access to a caring pediatric dentist, toothbrushes, fluoride, and every other component of the best care for a child you could hope for. I'm sure many of our readers who have raised or are raising children have had similar sentiments. I often think about the single parent. Perhaps she is working more than one job to support and care for her children. Those kids, perhaps, do not receive the same amount of parental or professional care and attention as my son. They may have a greater propensity for suffering from caries or other dental disease as a result, and the family may not have the resources to access the dental care to treat these diseases.

This month, many of us in the dental profession are aware of and, hopefully, are participating in Give Kids a Smile. In my mind, this has been the definitive shining star of the dental profession in the past 10 years. It has become a very visual and positive aspect of our public image. Much is publicized about the impact this program has on a global level. We will hear about how the Give Kids a Smile program increases access to dental care for a population of children who truly need it. It will serve as a springboard to send a message to policymakers that oral health is our nation's responsibility, not the dental profession's alone. Perhaps this year, Give Kids a Smile will spawn state and national legislative activity that will direct public resources in a way that we in the dental profession feel will best serve the oral health needs of all of our nation's children. Regardless, we will show the very best face of the dental profession and we can all take pride in the massive coordinated effort that dentistry puts forward to improve the oral health of America's kids.

But even as we celebrate and tout these global benefits, think for a moment about that little boy or girl in the dental chair for the first time, or the mom receiving toothbrushes for her children, perhaps their first. Behind the headlines of our profession's

Perhaps this year, Give Kids a Smile will spawn state and national legislative activity that will direct public resources in a way that we in the dental profession feel will best serve the oral health needs of all of our nation's children.

Age: 2. Brushing technique: Suspect.

newsletters and updates let us not forget there are individual lives that will be touched. There are parents who will come to know that there is someone, in fact an entire profession, on their side helping to look out for the oral health of their child. There are kids who may have never been shown how to brush their teeth who will learn for the first time. They may take the memory of their experience with one of the thousands of Give Kids a Smile volunteers and keep it with them for the rest of their lives. Good oral health habits learned may be passed down to their children and their children's children. The positive effects on individual lives as a result of our efforts this February are limitless.

So whether you are a dentist, hygienist, or assistant volunteering your services, or you are the president of a multimillion dollar dental company giving one of those oversized checks to a dental association president (can you really cash those things?), don't look too far beyond the face of the little boy or girl in the dental chair you are helping. And don't let February or the boundaries of the Give Kids a Smile program limit our efforts to help those who need a little extra help. Their oral health will need attention 365 days out of the year.

As my son sleeps now, I hope for a better tooth brushing experience tomorrow. At the end of the film *The Shawshank Redemption*, Morgan Freeman's character walks along a beach in Mexico, savoring his newfound freedom and, also, reflecting on hope. His words are simple, elegant, profound. In this spirit, I hope that the profession of dentistry can be a central force in solving the oral health care challenges facing this nation and the world. I hope that Give Kids a Smile will serve as an impetus for the leaders of our profession to shape public policy in a way that forces the oral health care needs of our nation's children to become a forethought, not an afterthought of policy decision makers. And I hope we all experience the joyous and satisfying feeling that we have touched and indeed, improved the individual lives of many needy children and their parents, one smile at a time. CDA

Access to Care for All

In the September 2005 issue of the *CDA Journal*, Christine Miller, RDH, MHS, MA, wrote an interesting article about "Access to Care for People With Special Needs." The abstract alluded to a population of special needs children of unknown number, but who are treated by only 10 percent of the general dentists. We then leave this population to discover that one-third of California's population (10.2 million) have no access to dental care. That's four times the population of the San Francisco Bay Area. And it's implied that the population will increase by 50 million, leaving us to calculate that 16.5 million Californians will have no access to care. Those are very big numbers that have no access to dental care. However, the middle of the article seems to be an argument to consider expanding duties for hygienists to include irreversible restorative duties to mainly care for schoolchildren. We are urged to believe that numerous studies have shown that training equivalent to the New Zealand School Nurse Program will allow hygienists to do procedures at a similar level of dentists. There is finally a quote at the end of the article that notes how we need to maintain and expand an adequate oral health work force in size, ethnicity, and linguistic competence to meet … the oral health problems of people with special needs.

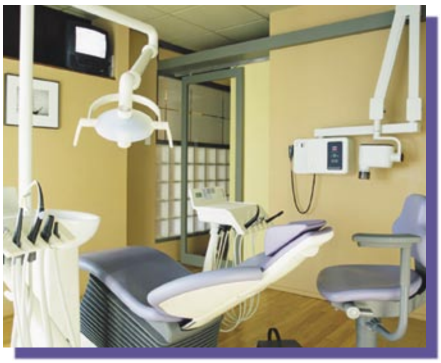
I don't know for sure, but I don't think that the quoted number of Californians have no access to dental care. Many Californians have less-than-perfect access, some may have no access, and certainly many poor and underprivileged special needs children and adults are underserved. But training hygienists to work as school nurses will not solve the problem. It certainly won't address the lack of care for patients with special needs. It will provide a small group of patients with irreversible dental care by those who are less fully trained than dentists. It may be equivalent, because it has been shown over and over that it is possible to train someone to do a specific thing that dentists do with less training than a dentist receives, until the bur follows decay into the pulp. Then it won't be a dentist able to provide comprehensive care that solves the more complex problem. And how will the size, ethnicity, and linguistic competence of this group bring any additional care to patients with special needs? As is pointed out in other articles in the same issue, dentists need to be trained far beyond dental school to adequately treat those with special needs. And some major changes in funding are necessary to get enough money to bring treatment to this population. Training additional dentists or other therapists will have no effect without funding. It's been shown that auxiliaries with expanded duties do not automatically and altruistically provide services to those with special needs without compensation.

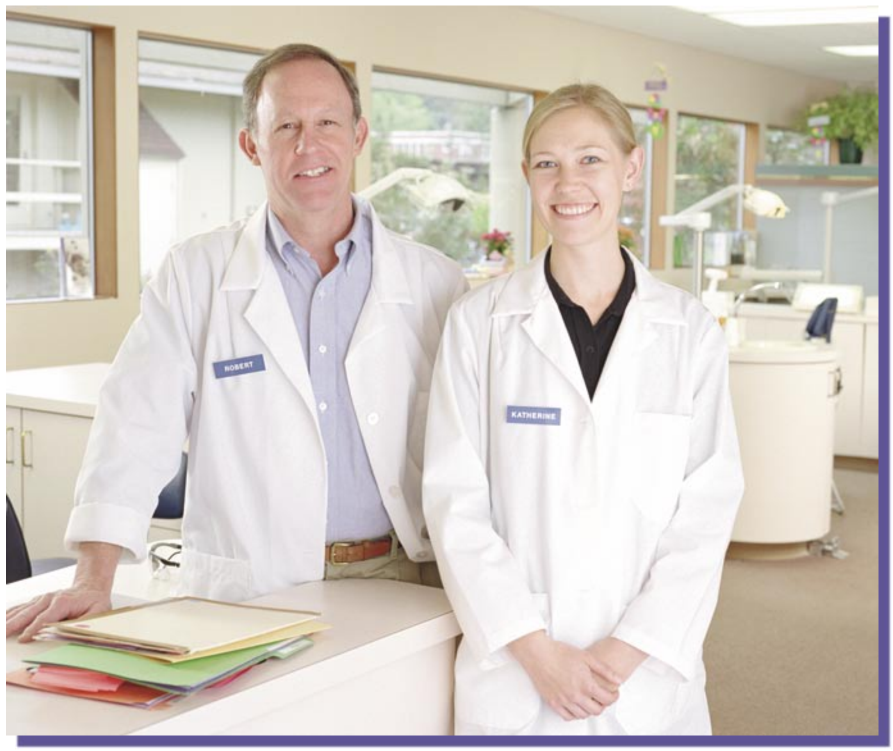
I find it irritating that an article uses the title of "special needs" to promote dental restorations by nondentists to patients in California or in any other ethnic, age, or health compromised group.

Working as a team, dentists, hygienists, assistants, and legislators can come up with a program to take care of everyone. Dentistry in the United States is the best in the world. It just isn't distributed perfectly. We should figure out a solution that offers all members of society, many the most needy and suffering, the opportunity to receive first-class care.

William A. van Dyk, DDS
San Pablo, Calif.

Working as a team, dentists, hygienists, assistants, and legislators can come up with a program to take care of everyone.





Supply of California Dental Hygienists and Assistants Is Stable, Despite Earlier Shortages

By Jon Roth, MROD, CAE

New studies, commissioned by the California Dental Association Foundation, indicate that the supply of dental hygienists and dental assistants has stabilized, despite a significant shortage that occurred in the late 1990s.

The studies were conducted by the University of California Los Angeles Center for Health Policy Research and University of California Berkeley's Nicholas C. Petris Center for Health Care Markets and Consumer Welfare, two of the leading health policy centers in the state.

Results from these studies indicate that while a small number of private practice dentists still encounter difficulty hiring qualified staff, the profession is rebounding from earlier shortages. Findings also demonstrated that there was indeed a shortage in both dental hygiene and assisting groups around the year 1999. The labor shortage for dental hygienists was alleviated by 2002, while the labor shortage for dental assistants was alleviated in 2001.

Dentists' perceptions of shortage, however, have remained rather high with 72 percent of dentists without openings and 89 percent of dentists with openings perceiving that a shortage exists. Most dentists in California believe there is still a shortage of dental hygienists and assistants, but these perceptions are most likely due to their past experience, not current labor market conditions.

Researchers at the UCLA Center for Health Policy Research examined delays in hiring allied dental personnel and other staffing issues through a survey of approximately 13,600 general dentists throughout California in 2003. They found that:

■ Only half of California dentists employed hygienists.

■ Only 11 percent of dentists experienced delays in hiring qualified hygienists and only 20 percent had similar delays in hiring assistants.

■ Experiences of shortage were more frequent in the greater San Francisco Bay Area, the Sacramento Area, and Southern California counties other than Los Angeles.

■ The perception of a shortage of dental hygienists and assistants was widespread, even among dentists without openings, and those with openings but no shortage experience.

The UC Berkeley research team analyzed shortages from the perspective of labor economics, using longitudinal data from 1997-2005. They found that:

■ An increased demand for dental services between 1997 and 2004 also was accompanied by an increase in demand for hygienists and assistants, as would be expected.

■ Between 1999 and 2002, the average wages of hygienists rose 48 percent and 28 percent for assistants, a key indicator of shortage in that timeframe.

■ Since 2002, however, wages have stabilized for hygienists and even returned to pre-1997 levels for assistants indicating that the labor shortage is alleviated.

The joint findings are a starting point for further investigation of allied dental health personnel supply and demand, as well as forecasting the provision of care into the future. These studies mark the beginning of a series of inquiries by the CDA into the complex linkages between oral health demands in California and the workforce capacity to effectively deliver the provisions of care today and in the future.

In addition to this study, the CDA is working with the Center for the Health Professions at the University of San Francisco to investigate contributing factors in decisions of dental hygienists to enter, remain, and exit the workforce at various intervals in their career. Additional projects through UC Berkeley also are being pursued, which will develop forecasting models for future workforce capacity and demands on the dental profession given the evolving demographic and socioeconomic changes in California's population.

To receive a free copy of the CDA Foundation workforce studies, visit www.cdafoundation.org/study.

No Changes in Wisdom Teeth Recommendations

Third-molar research receiving recent media attention advances dentistry's message on the importance of good oral health, and leaves practice recommendations unchanged regarding wisdom teeth, according to a statement by the American Dental Association.

While the research suggests that individuals who keep their wisdom teeth might be more likely to develop periodontal disease in that area of the mouth, it is premature to speculate that gum disease in these instances might lead to other health problems, according to the ADA press statement. (The ADA statement and information about wisdom teeth and other oral health topics are available in the "Your Oral Health" content area of www.ada.org.)

Research announced by the American Association of Oral and Maxillofacial Surgeons at a press conference in Boston last fall received coverage in the *Washington Post*, *Atlanta Journal-Constitution* and from Scripps Howard News Service, *Newsday*, WebMD online, and smaller media outlets. The research called into question whether young adults who keep their wisdom teeth might be at risk for future health problems such as heart disease, diabetes and, for women, preterm birth.

"Although intriguing, the issue needs more study and, therefore, the ADA agrees with the AAOMS that no changes in practice recommendations regarding wisdom teeth are needed at this time," according to the ADA. "This research does serve to raise awareness of the importance of maintaining good oral health."

"This research does serve to raise awareness of the importance of maintaining good oral health."

— ADA

Partial Pulpotomy Is Preferred for Immature Permanent Teeth

When performing a pulpotomy on an immature permanent tooth, it's important to use a technique that preserves as much vital pulp as possible so continued physiologic dentin deposition and complete root formation can take place, said Julie Russo, DMD, in an issue of *Today's FDA*, journal of the Florida Dental Association. A partial pulpotomy falls somewhere between pulp capping and a complete pulpotomy, with only the outer layer of damaged tissue removed. "Recent studies have shown partial pulpotomies have high success rates in cariously exposed teeth, and in teeth that have crown fractures," Russo said.

Among the indications for a permanent tooth partial pulpotomy:

- No history of spontaneous pain,
- Acute minor pain that subsides with analgesics,
- No discomfort to percussion, no vestibular swelling, and no mobility,
- Periodontal attachment normal on radiographic examination,
- Pulp exposed during caries removal,
- Tissue appearing vital, and
- Bleeding from pulp excision site stopping within two minutes with irrigation.

A partial pulpotomy is preferred for immature permanent teeth, Russo said because it preserves the cell-rich coronal pulp tissue, which has a better healing potential and can help the tooth develop normally.

Accurate Records, It's a Good Thing

When it comes to patient records, dentists oftentimes say that making improvements is at the top of their "To-Do" lists. However, many of them keep putting it off.

This can be a mistake, wrote Lee Johnston in an issue of the West Michigan District Dental Society's *Bulletin*.

"Improving records costs money and takes time," said Johnston, president of the society's subsidiary WDA Professional Services, Inc., but "the quality of your records can be important in peer-review cases, lawsuits, and even disagreements with your local lab."

Johnston advised dentists to have patients fill out medical history forms every two or three years, unless state law requires differently. Patients often tell dentists that nothing has changed in their medical profile even though they may be taking a new prescription drug. However, if filling out a form, it may be easier for them to remember this fact.

Accurately completed, signed, and maintained patient records can mean the difference between winning and losing in a malpractice suit. In addition, Johnson added that good dental records could keep a lawsuit from even reaching court.

"Take time to review your medical history and related forms now," Johnson said. "It could save you problems later."

Clinical Trial Agreement Reached for Oral Cancer Detection Drug

Zila Inc. announced that it has reached an agreement with the U.S. Food and Drug Administration on the design and size of its new Phase III clinical trial for OraTest, an oral cancer detection drug.

The agreement, reached under the FDA's Special Protocol Assessment process, permits Zila to begin its new Phase III clinical trial. The special protocol assessment is a process that allows for official FDA evaluation of a Phase III clinical trial protocol and provides trial sponsors with a binding, written agreement that the study design, including size, is acceptable to the FDA.

The special protocol assessment process is intended to finalize the design and size of a clinical trial with respect to a drug's primary efficacy endpoint. A significant component of the new OraTest Phase III clinical trial is the classification of severe dysplasia as a "true positive" finding in the study (in addition to carcinoma in situ and cancer). This and certain other elements of the new clinical trial protocol will permit enrollment of fewer patients and fewer visits than originally anticipated.

Take-up Rate High for Dental Benefit Plans

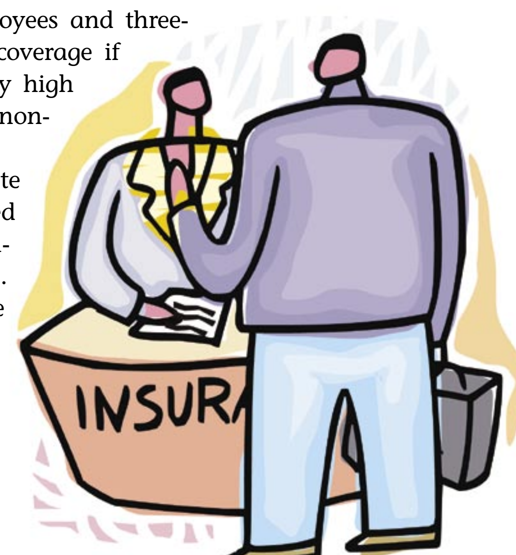
When employers offer dental benefit plans, nearly eight in 10 workers participate, regardless of income, occupation, residence, or employment status.

In March 2005, the dental insurance take-up rate for all workers was 78 percent, according to a report from the U.S. Department of Labor's Bureau of Labor Statistics. The take-up rate is an estimate of the percentage of workers with access to a plan participating in the plan.

Less than half the nation's workers, 46 percent, have on-the-job access to dental benefit plans, and only 36 percent participate in such plans, says the BLS national compensation survey of employee benefits. However, the take-up rate is uniformly high among union and nonunion, white- and blue-collar occupations and full- and part-time employees, though it dips to a 62 percent low for part-time workers.

Some 92 percent of labor union employees and three-in-four nonunion workers opt for dental coverage if offered. The participation rate is uniformly high across the country and in metropolitan and non-metropolitan areas.

Seventy percent of workers in private industry had access to employer-sponsored medical care plans, and 53 percent participated in medical care plans in March 2005. The BLS data set provides comprehensive measures of occupational earnings, compensation cost trends and details of benefit provisions. The report on employee benefits in private industry is posted online at the Bureau of Labor Statistics website, www.bls.gov.



Mission of Mercy Scheduled for New Orleans

The dental associations of Kansas, Texas and Virginia, along with the Open Door Dental Clinic of Alamance County in North Carolina, have joined forces to manage the dental care portion of what may be the biggest-ever dental and medical health fair in history held in New Orleans.

The ADA Foundation has provided a $50,000 grant for the project, and there have been donations of supplies and equipment from a number of donors to support the project.

Potentially the largest, free medical and dental clinic, organizers expect to treat more than 10,000 people with a variety of health care services. Organizers hope to fill 125 dental chairs each day (an estimated 6,000 patients) during the event held Feb. 6-11. Patients include the uninsured, underinsured, Medicaid enrollees, and citizens who temporarily come to New Orleans to help rebuild the area and may be in need of care.

The participating dental associations and the Open Door Dental Clinic of Alamance already conduct Mission of Mercy dental clinics in their respective home states.

"A few months ago, there was an outpouring of volunteers who wanted to help out but could find nowhere to go after the hurricane, said Terry Dickinson, DDS, executive director of the Virginia Dental Association, in a press release. "Through the Mission of Mercy, this is a chance to help."

In December, organizers put out a call for dentists, dental hygienists, assistants, lab technicians, and office staff to participate. "Come for one day, come for all the days, get in the heart of where it all happened and help some folks; give them a little extra boost," Dickinson said. "All volunteers have to do is get here."

Organizers estimated to need the services of at least 100 dentists and support staff per day. Dickinson said senior dental students from Virginia Commonwealth University School of Dentistry would attend, adding that students can get a glimpse of how important it is to give back to the profession and helping volunteers to serve as mentors "and to see what a great future the profession has."

Volunteers Needed for Online Directory

With a goal to assemble the largest health care provider network benefiting those with mental disabilities in North America, Special Olympics recently unveiled the online Healthy Athletes Provider Directory.

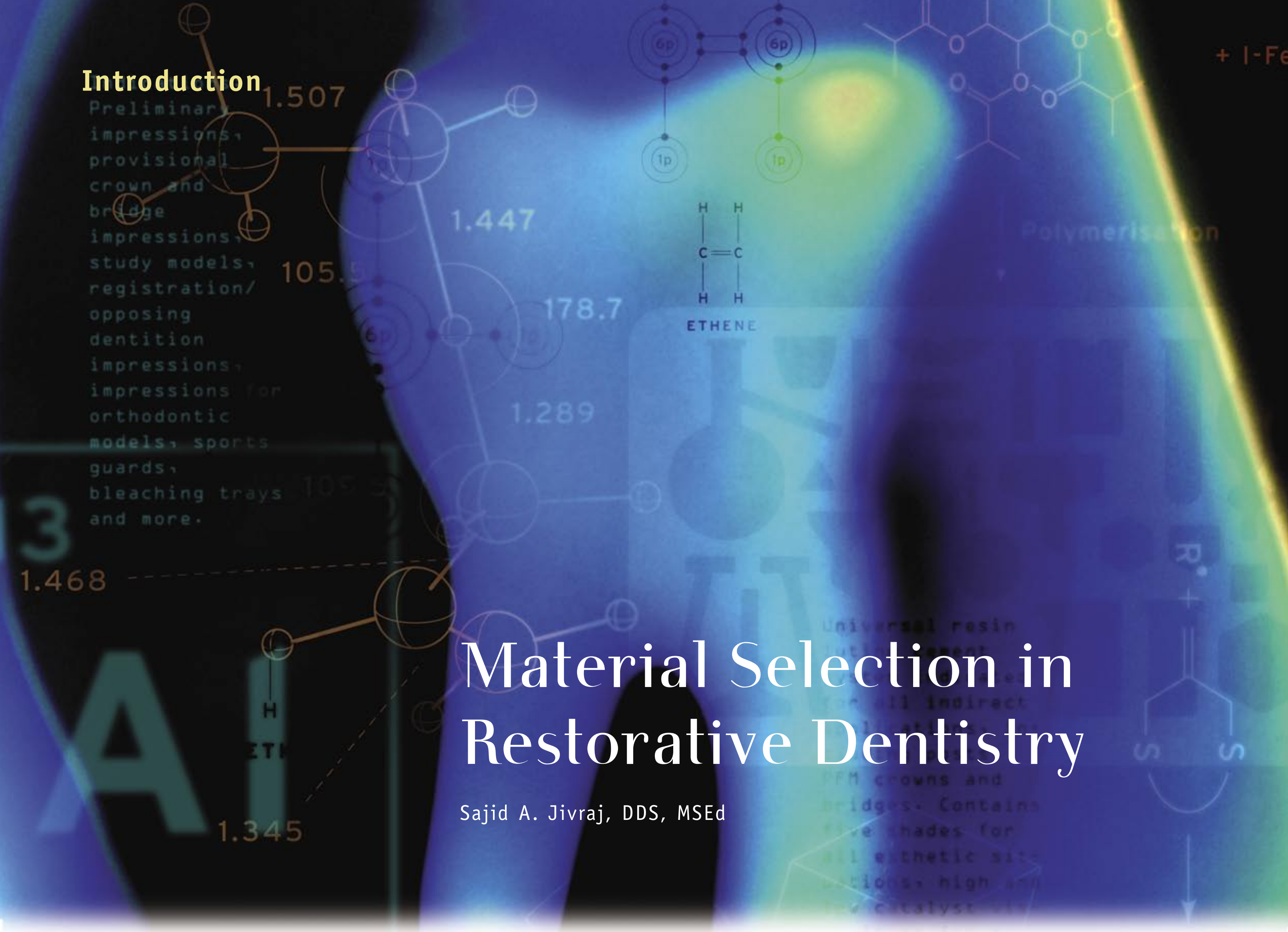
The database allows health care providers to voluntarily identify themselves as willing to be contacted about treating those with mental disabilities. To sign up, providers simply go to www.specialolympics.org/providerdirectory and input a minimum of information. Individuals will be able to search the database when it is available later this year.

Upcoming Meetings 2006

March 15-18	Academy of Laser Dentistry's 13th Annual Conference and Exhibition, Tucson, www.source2006.org.
March 26-April 1	United States Dental Tennis Association Spring Meeting, St. Petersburg, Fla., www.dentaltennis.org.
April 27-30	CDA Spring Session, Anaheim, (866) CDA-MEMBER (232-6362).
May 16-20	American Academy of Cosmetic Dentistry 22nd Annual Scientific Session, San Diego, (800) 543-9220.
May 22-27	Academy of Prosthodontics 88th Annual Scientific Session, San Francisco, www.academyprosthodontics.org.
Sept. 15-17	CDA Fall Session, San Francisco, (866) CDA-MEMBER (232-6362).
Oct. 16-19	ADA Annual Session, Las Vegas, (312) 440-2500.
Dec. 3-6	International Workshop of the International Cleft Lip and Palate Foundation, Chennai, India, (91) 44-24331696.

To have an event included on this list of nonprofit association meetings, please send the information to Upcoming Meetings, *CDA Journal,* 1201 K St., 16th Floor, Sacramento, CA 95814 or fax the information to (916) 554-5962.

Introduction



Material Selection in Restorative Dentistry

Sajid A. Jivraj, DDS, MSEd

During the 1960s and 1970s, few dental materials were available for the restoration of carious, fractured or missing teeth. As a result, occlusal forces were sustained using amalgam and gold restorations. Although these restorations provided an extremely functional restoration, creation of an esthetic form from a patient perspective was often difficult.

Biomaterials science is in the midst of the largest transition in history. Significant advances have occurred in the development of both direct and indirect tooth-colored restorative materials. With this transition has come a paradigm shift in material selection. Patients are demanding tooth-colored restorative materials. These materials have had an undeserved poor reputation. This has been largely due to improper clinical manipulation and not to the material itself. Attention to detail and precise clinical manipulation will result in longevity of these restorations, which rival the traditional metallic restorative materials.

As the evolution of materials and technology continues, dental education will require modification in order to incorporate the changes suitably into the curricula.[1] Dental schools will need to adopt a more flexible and dynamic curriculum that emphasizes basic sciences and principles rather than a specific technique. Emphasis will need to be on clinical manipulation rather than memorizing compressive and tensile strength values.

Teaching critical thinking skills is imperative if newly graduated dentists are to avoid the pitfalls of relying too heavily on manufacturer-driven data. Manufacturers readily provide data regarding strength and a variety of other properties. At times, they also provide the results of short-term clinical trials. How reliable is that information? More importantly, how useful is it? It has been the goal of many dental materials scientists to predict the clinical performance of dental materials based on physical properties.

Unfortunately, success has been elusive. We know today that improvements in physical properties alone are not good predictors of clinical performance. Clinical trials are the most reliable source of information. One must also ask the question of how long should a clinical trial be before one accepts the conclusions. The dynamics of dental materials testing is such that by the time experimentation is complete, a new product is ready to be launched. This creates a vicious cycle of not enough data vs. no data. How does the practicing clinician

Guest Editor / Sajid A. Jivraj, DDS, MSEd, is chairman of the Section of Fixed Prosthodontics and Operative Dentistry, University of Southern California School of Dentistry. He also maintains a private practice limited to prosthodontics in Sherman Oaks and Torrance, Calif.

make a choice? If we look at the literature on longevity of all ceramic crown systems, it is a basic fact that sufficient data is not available to the clinician until many years after a system is introduced to the profession.

Clinicians wishing to utilize new systems in the absence of clinical data should proceed with caution. Systems should be analyzed in terms of their ability to provide improved esthetics and their potential for longevity. Experts in the field should be consulted, and a thorough knowledge of the system requirements (preparation design, requirements for bulk reduction, margin geometry, etc.) should be obtained from the manufacturer. It would seem prudent to then use the system (with the appropriate informed consent) in a few patients, and then to observe the results before placing a large number of such restorations. Placing large numbers of essentially experimental restorations is unfair to patients and potentially very expensive for the clinician.[2]

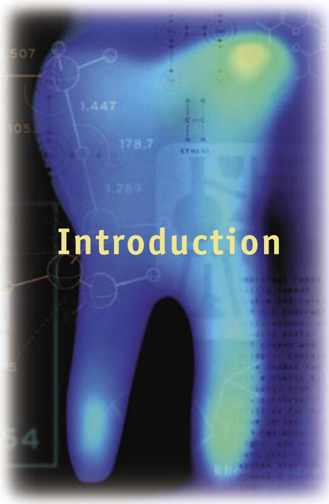
The profession will be more dependent on continuous updates and accumulated experience in order to remain current, and to subsequently provide the population with the benefits of high-tech materials and treatment methods.

In this issue, Dr. Pascal Magne will critically evaluate material choices for posterior restorations. Drs. Tae Kim, Terry Donovan and I will discuss the decision-making process in choosing a luting agent. Dr. Donovan also will look at the longevity of the tooth restoration complex and the factors the clinician needs to take into account prior to choosing a restorative material.

My intention with this issue is to stimulate critical thinking and to inspire readers to challenge manufacturer-driven data so that appropriate materials are selected and patients given the best possible care. CDA

References / 1. Nathanson D, The impact of biomaterials and research on dentistry. *Pract Periodontics Aesthet Dent* 12(1):68,70, January-February 2000.

2. Donovan TE, Cho GC, The role of all-ceramic crowns in contemporary restorative dentistry. *J Calif Dent Assoc* 31(7):565-9, July 2003.



Evidence-Based Dentistry, Dentists, and Dental Materials

Terry E. Donovan, DDS

The profession of dentistry has changed dramatically in the 39 years since I graduated from dental school in 1967. Some of the changes have been wonderful and include the well-documented reduction in dental caries amongst large segments of the population, the development of predictable adhesive restorative dentistry permitting minimally invasive procedures, and the discovery of predictable osseointegration with titanium implants, which has significantly changed approaches to treatment planning.

In my opinion, other changes have had a negative contribution. Some of these include the increase in advertising and direct marketing by professionals to the public, and the frank commercialization of dentistry that has become apparent in recent years. Other changes have been equivocal, with both benefits and negative effects. The tremendous emphasis on esthetics that has consumed both society in general and the dental profession specifically has both a positive and a dark side. Practitioners are thrilled and gratified by being able to dramatically improve a patient's smile and overall esthetic appearance, often in a minimally invasive manner. With proper data collection, diagnoses, treatment planning, and execution, it is possible to take very difficult clinical situations and transform them into smiles of beauty through complex multidisciplinary therapy that may take many months or even years of treatment. On the other hand, we have seen "complete makeover" treatment plans that represent unacceptable compromises in the long-term quality of care. We also have witnessed atrocities of unnecessary treatment trumpeted in some of the trade publications where patients receive 28 units of unneeded bonded ceramic restorations in two appointments based on a misguided preconceived notion of an optimal occlusal position that is not supported by the scientific literature. One wonders if adequate informed consent was given by patients in these situations.

One area that has become a source of considerable confusion for practicing dentists is that of selection and manipulation of contemporary dental materials. Many years ago when I first began practice, there were only a handful of materials to choose from. Manufacturing firms were managed by scientists and generally, products had considerable clinical testing prior to being brought to market. Today, most of the dental manufacturers are part of a large multinational conglomerate, and most are dominated by marketers who are primarily responsible for the financial bottom line. Products are being brought to the market with virtually no clinical testing. In fact, general dentists are doing the clinical trials for the manufacturers, without the protection normally afforded by industrial review boards.

Guest editor / Terry E. Donovan, DDS, is professor and director, Advanced Education in Prosthodontics, and co-chairman, Division IV, Primary Oral Health Care, University of Southern California School of Dentistry.

Practitioners must be cautious of claims made by manufacturers or manufacturer's shills and must demand that appropriate "evidence" be generated before using new products. For most restorative materials, that "evidence" should come from properly conducted clinical trials. The reality is these clinical trials are rarely, if ever, conducted. This is partially because of the inherent expense involved, and partially because of the time required to generate meaningful data. By the time the trial is conducted and the article describing data from the study submitted for publication, most materials will have evolved into a substantially different product, and the generated data will be of minimal value.

For example, the exponential development of dental cements has caused considerable confusion amongst many practitioners. Several years ago, a number of manufacturers introduced new resin-modified glass ionomer cements to the profession with the usual accompanying claims and marketing hype. Several brands have now stood the test of time and are used extensively for the cementation of cast gold and porcelain fused-to-metal restorations. However, one specific brand, introduced by a reputable manufacturer, had a significant problem of postcementation expansion. This was caused by the hydrophilic nature of one of the cement's components, and water sorption resulted in postcementation fracture of all-ceramic crowns and some teeth restored with cemented dowels and cores. (Resin-modified glass ionomer cements should really not be used in these specific situations). Needless to say, both the manufacturer of the cement and the general dentists have been subject to a considerable amount of litigation, which is time-consuming, costly, and emotionally draining.

There is plenty of blame to share in this example. The manufacturer should not have brought the product to market without more extensive testing, and should have recalled it as soon as anecdotal reports of catastrophic failure began to appear. Gurus should not have recommended use of this cement in the absence of any amount of clinical evidence. And finally, dentists should not have been using that type of cement in those specific clinical situations, and certainly should not have been using a new type of cement that had virtually zero clinical documentation. At the time, there were plenty of reliable, time-tested cements available.

Today, we have a similar situation with adhesive bonding agents. Dentists and manufacturers seem to have lost sight of the fact that the most critical bond in adhesive restorative dentistry is the acid-etched enamel-resin bond. Many contemporary (sixth or seventh generation) dentin bonding agents seem to have solved the problem of postoperative sensitivity, but don't provide an adequate bond to uncut enamel (which is responsible for sealing the margins). Technique modifications can likely solve this problem, but in the meantime, dentists who have used these agents are anecdotally reporting staining of the enamel margins as a function of time. This, of course, is a sign of microleakage that will likely eventually lead to recurrent caries.

> Practitioners must be cautious of claims made by manufacturers or manufacturer's shills and must demand that appropriate "evidence" be generated before using new products.

One additional contemporary area of confusion is that of all-ceramic crowns. Currently there are a myriad of all-ceramic systems available, and all are being aggressively marketed with undocumented claims of superiority and longevity. Most dentists in North America continue to utilize porcelain-fused-to-metal restorations, PFMs, as the predominant esthetic restoration in their practices because these restorations provide the best combination of reasonable esthetics with maximum longevity. However, because of the intensity of the marketing for all-ceramic restorations, many of these same dentists feel somewhat insecure about the decision to continue to use PFMs. While a few of the contemporary all-ceramic systems can provide a superior esthetic result, and most are stronger than a traditional feldspathic porcelain jacket crown, the truth is that an all-ceramic restoration will generally have a shorter life span than a PFM.

Practitioners must understand that the primary mode of failure for all-ceramic crowns is fracture, and that providing a stronger material does not necessarily improve the rate of survival. This is because ceramic restorations fail due to propagation of microscopic defects (Griffith's flaws) that are inherent in the restoration due to the fabrication process. Thus, a material may possess dramatically superior physical properties such as compressive strength, flexural strength, fracture toughness, etc., but this will not automatically translate into superior clinical performance unless the fabrication process results in the elimination of flaws.

It has been proposed that clinicians should only consider using an all-ceramic system when clinical trials have established a survival rate of 95 percent at five years.[1] Almost none of the currently available all-ceramic systems can satisfy this criterion, especially if posterior tooth restorations are considered.

The current call for practitioners to practice evidence-based dentistry is laudable and must continue. The evidence base available is sadly deficient and not readily accessible to the average practitioner. What evidence is available must be conceptualized into a working philosophy for the general practitioner. And, it should be clearly understood that the general practitioner is faced with additional overwhelming challenges.

First, they find themselves managing a serious small business, which they were never educationally trained to manage. This is extremely stressful, and is only complicated by the myriad of bureaucratic regulations that have been enacted in recent years. In addition, the practitioner often must also manage a large staff with emotional differences that Freud could not comprehend, and these practitioners also have nondental lives where they attempt to be exemplary husbands/wives, mothers/fathers, coaches, scout leaders, etc. Given that these significant demands are a reality for most dentists, it seems unreasonable to expect that they can keep pace with the current epidemic of peer-reviewed literature. Thus, practitioners must adopt a strategy that will allow them to provide dental care that is reasonably evidence-based.

It is clear that clinicians must adopt a cognitive strategy to survive in the contemporary environment. First, general dentists should make the conscious decision that they do not want to practice "at the leading edge." This is a role that should be played by researchers and universities. New products should be tested in well-designed clinical trials where patients give true informed consent, and both the treating dentists and patients are protected by trial reviews by existing IRBs.

Second, dentists must become skeptical consumers of information provided by manufacturers and lecturers, who are often simply shills for industry. They must demand valid clinical evidence for materials and procedures, and in the absence of such data, should refrain from using the recommended products. Quality continuing dental education is important in this process, and practitioners should listen to the "experts." Again, the dentist is cautioned not to accept blindly the recommendations of lecturers, and to learn to listen to the "experts" with a healthy level of skepticism. It must be sadly noted that many so-called "experts" are simply paid shills for manufacturers and the fact that they are being paid to deliver a specific message is often not disclosed.[2]

The dentist is cautioned not to accept blindly the recommendations of lecturers, and to learn to listen to the "experts" with a healthy level of skepticism.

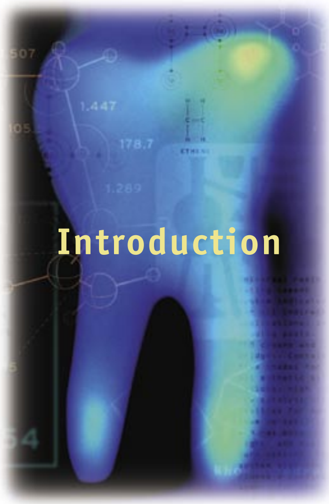
Once dentists have decided to utilize a new product or material in the practice, it is incumbent upon them to be certain they understand the nature of the product. Is there a specific preparation design essential to success? Is there a specific required margin configuration or luting protocol? Finally, the clinician has the responsibility of introducing the new product/material into the practice in a graduated sequence. Wherever possible, the product should be used experimentally on an extracted tooth, so that the clinician becomes familiar with the manipulative characteristics of the material. It should be used in a few situations where it is clearly indicated and the results evaluated. If the initial results are positive, then it might be tried an a few situations where the envelope of comfort is being pushed. After evaluation of the clinical results, coupled with evidence external to the practice, the intelligent clinician will then establish the utility of the product in their practice.

In summary, the contemporary dentist has an exciting armamentarium of materials and techniques with which to help patients. New materials and techniques are being introduced at an exponential rate. Manufacturers have the responsibility to adequately test materials before introducing them to the market, and also have the responsibility to factually represent their products in their marketing.

Lecturers have the responsibility to research the facts regarding materials and clearly indicate to their audience what statements are supported by evidence and which statements are merely opinions. They also must disclose any financial connections they have with manufacturers or with specific products. Dentists cannot afford to be passive consumers of information from either manufacturers or "experts." They must exercise healthy skepticism, and demand that information providers support their recommendations with reliable clinical evidence. We can only continue to provide ethical, evidence-based dentistry for our patients if all parts of the "team" live up to their clearly defined responsibilities. CDA

References / 1. Scharer P, All-ceramic crown systems: Clinical research versus observations in supporting claims. *Signature* 1-3, 1996.

2. Donovan TE, Promising indeed: The role of "experts" and practitioners in the introduction and use of new materials and techniques in restorative dentistry. *J Esthet Rest Dent* 16:333-4, 2004.



Longevity of the Tooth/ Restoration Complex: A Review

Terry E. Donovan, DDS

Abstract

The contemporary dentist has a wide variety of materials to utilize in the restoration of defective teeth. The decision as to which restorative approach should be utilized in any given clinical situation is a joint one between the patient and the treating dentist. The dentist's primary obligations are to understand the indications and contraindications of various materials, understand how to optimally manipulate those materials, and educate the patient so that they make intelligent decisions and give proper informed consent. The ultimate decision as to which approach to use rests with the patient, and the patient must clearly understand the benefits and risks associated with different restorative options. Clearly, one of the important considerations with any treatment is the prognosis and restoration longevity. When attempting to predict the long-term prognosis of any restoration, it is important to consider both the restorative material being considered as well as the specific tooth that is being restored. Many times the amount of remaining tooth structure has a more significant bearing on long-term prognosis than what material is used for restoration. Thus, the tooth/restoration complex must be considered as a whole when predicting potential longevity. Many clinical trials have been conducted to attempt to answer those questions, and relatively few unbiased, unambiguous answers are available. The only completely honest answer to those questions is *"It depends."* This is because the prognosis of all restorative therapy depends on the complex interaction of a number of variables, some of which are controlled by the dentist, and some of which are totally out of the dentist's control. This article will attempt to delineate some of the factors related to the long-term prognosis of the tooth/restoration complex, and specifically identify factors that decrease the prognosis of the tooth/restoration complex.

There are five main groups of factors to consider when attempting to determine the prognosis of restorative therapy (**Table 1**). The first consideration is what material is being used? Second, there are a number of factors related to the treating dentist. Third, there are a number of critical factors specific for each individual patient. There are also a number of variables that are important related to the tooth or teeth that are to be restored. And finally, with indirect restorations, there are variables associated with the laboratory technician.

Failures of restorations may be classified as biologic or mechanical.[1,2] Biologic failures include recurrent caries, loss of periodontal support, biologic width violations, and pulpal involvement. Mechanical failures include tooth or cuspal fracture, restoration fracture or fracture of a veneering material, excessive wear, and loss of retention of the restoration. Most intraoral mechanical failures are a result of fatigue failures that begin with crack initiation and proceed with slow crack propagation to eventual clinical failure.

Many of the biologic factors relate to restoration contour, fit, and mar-

Guest editor / Terry E. Donovan, DDS, is professor and director, Advanced Education in Prosthodontics, and co-chairman, Division IV, Primary Oral Health Care, University of Southern California School of Dentistry.

Figure 1. All-ceramic crowns fail by defect propagation, and the prognosis for such restorations on posterior teeth is guarded.

Figure 2a.

Figure 2b.

Figure 2. These conservative cast gold restorations have been in service more than 35 years. *(Photos courtesy of Drs. R.V. Tucker and R. Simonsen)*

Table 1

Factors Related to Tooth/ Restoration Longevity

- Restorative material
- Ability of the dentist
- Patient factors
- Tooth factors
- Dental laboratory factors

gin location, which are controlled by the dentist. Biologic failures also are caused by patient factors that are more or less out of the control of dentists. Mechanical failures relate to the care and skill of the dentist and laboratory technician, and also to parafunctional habits of the patient. Some failures, of course, are both biological and mechanical. Often, undetected recurrent caries may result in clinical fracture of the tooth, and vice versa, untreated cuspal fracture can lead to leakage and recurrent caries.

Material Factors

The choice of material has a clear influence on the expected longevity of a restoration. A metal restoration would, in general, have a longer expected lifespan than a ceramic restoration primarily because metal restorations are normally not susceptible to fatigue. Metal-ceramic crowns would be expected to have superior survival rates than all-ceramic alternatives because of their ability to resist flaw propagation (**Figure 1**). Intuitively, materials with improved physical properties would be expected to perform better than a similar material with poorer physical properties. However, it is clear that the correlation between improvements in physical properties and clinical performance for most materials is poor.[3-5]

One important materials-related factor is its relative level of technique sensitivity.[6] A material is described as "technique-sensitive" when the clinical results achieved with the material have a high level of variability. It could rationally be argued that technique sensitivity is a dentist variable rather than a materials variable. This is because materials with low-technique sensitivity essentially neutralize the dentist factor in determination of the result. Dental amalgam has a very low level of technique sensitivity and it is likely that every recent graduate from every dental school in North America can place a serviceable amalgam that will provide a good service for their patients.[7] This lack of technique sensitivity is primarily a result of percolation and buildup of corrosion products at the amalgam/ tooth interface, which results in a self-sealing process independent of the operator. On the other hand, composite resin materials have a high level of technique sensitivity, and it is doubtful that all recent graduates will be as successful using composite resin. Properly placed, in small to intermediate cavities, composite resin can provide a service equal to, or perhaps superior to, dental amalgam.[8] However, it is likely true that a considerable percentage of posterior composite restorations are not "properly placed."

Cast gold restorations can also be described as technique-sensitive. Cast gold restorations can provide an exceptionally long service, again assuming they are properly placed (**Figures 2a and 2b**).[9] However, while some clinical studies have reported excellent long-term results with cast gold restorations, others have reported less positive data.[10-14] The surprising differences in the results of these studies are primarily attributable to differences in the experience, discipline, and ability of the operators.

Dentist Factors

Data from clinical studies is often treated with a statistical analysis that reports the results in terms of a mean or average. However, it is increasingly clear that neither patients nor dentists neces-

Figure 3a.

Figure 3b.

Figure 3. Patients abusing methamphetamine often present with rampant caries.
(Photos courtesy of Dr. Jinus Emrani)

sarily conform to the median. In dental school, in most properly evaluated courses, dental students' grade scores will fit into some sort of bell curve, with some students achieving very high scores, some lower scores, and most will be grouped somewhere in the middle. Student achievement in any given course is related to a number of variables, including the student's interest in the subject, the quality of the instruction, the effort invested by the student, the student's inherent intelligence and clinical ability, external personal factors, and also the quality of the evaluation.

The quality of restorations placed by a dentist is similarly affected by a significant number of variables. As much as we do not want to believe it, all dentists are not equal. The current standard for graduation in dental education is that students meet the criteria for minimum competency. As a result, there are significant differences in dentists' basic knowledge base when they graduate from dental school, and that gap often widens in the years following graduation. Despite mandatory continuing dental education that is in place in most jurisdictions, there are huge variations in the approaches taken by dentists to participate in postdoctoral education. The best dental students don't necessarily continue to expand their knowledge base, and often average dental students gradually become outstanding dentists as they pursue a committed, consistent course of continuing education. One of the optimum strategies for continued improvement is attending hands-on courses and study clubs with master clinician mentors.

An oft repeated phrase used by dental educators is, "First, do the right thing, then, do the thing right." (Personal communication, Dr. William McHorris, 1986). Dentists require both knowledge and experience to do the right thing, and need knowledge, experience, and skill to do the thing right. In spite of extensive efforts to put dentistry on a more scientific level, much of what we do continues to have a significant artistic component. Dentists vary considerably in their level of skill, and probably more importantly in their discipline to pay meticulous attention to detail. Those clinicians who combine superior knowledge, skill, and discipline will likely attain better and longer lasting results, especially with materials that are classified as technique-sensitive.

Dentists also vary considerably in their communication skills. This affects their ability to motivate patients to return regularly for required maintenance, perform adequate oral hygiene procedures, diet control, smoking cessation, and their ability to command an adequate fee to allow them to perform restorative dentistry at a high level. Variations in these communication skills clearly can positively and negatively affect the long-term outcome of care, independent of the quality of the initial restoration. Communication skills can also influence the acceptance or lack of acceptance of proposed treatment plans, as well as compliance with regular use of occlusal night guards. The prognosis for restorations in patients with nocturnal bruxism is severely compromised with poor compliance related to use of an occlusal night guard.

Patient Factors

Just as there are considerable differences among dentists, there are enormous differences among patients. Factors that might affect the prognosis of restorations and outcome of care include the personality type, hygiene habits, diet, abuse of alcohol, prescription or recreational drugs, systemic health, medications, parafunctional habits, individual susceptibility to disease, esthetic expectations, and their interaction and relationship with their treating dentist. It is important to understand that every patient is unique, and the prognosis for restorative therapy is dependent on these patient-related factors, as well as a number of independent factors.

Even excellent restorative dentistry will fail if the patient fails to maintain a reasonable level of oral hygiene, or if they consume a diet with excessive amounts of refined carbohydrates and

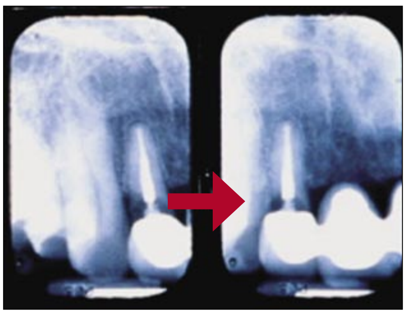


Figure 4. Crowns will not protect the teeth of patients with bulimia.

Figure 5. Bruxism patients must be provided with a custom mouth guard to protect the teeth and restorations. *(Photo courtesy of Dr. R. Furuichi)*

acidic foods. Few restorations can survive the ravages of severe nocturnal bruxism unless a night guard is fabricated and utilized regularly. Patients who abuse recreational drugs, such as methamphetamines, often have rampant dental caries (**Figures 3a and 3 b**). Recurrent caries often occurs around excellent restorations in patients with significantly reduced salivary flow resulting from pathology or as a side effect of use of many different medications for the treatment of systemic disease. Similarly, tooth structure beneath complete veneers crowns is often dissolved away in bulimic patients who continue chronic vomiting after restorative therapy has been completed (**Figure 4**). Patients who smoke have higher failure rates with osseointegrated implants than those who do not smoke.[15]

Another significant patient factor is bruxism. There is evidence that the majority of patients engage in some amount of bruxing activity, but the amount and severity varies greatly.[16] The most common forms of bruxism are diurnal (daytime) and nocturnal (sleep) bruxism. Nocturnal bruxism is by far the most destructive, as normal conscious inhibition mechanisms are not active and tremendous bite forces can be generated. Average bite forces measured in bite force studies range from 150-175 psi for diurnal bruxism, and 900–1,000 psi in nocturnal bruxism. Both the force and duration of the applied force can be elevated in nocturnal bruxism.[17,18]

The prognosis for any restoration is reduced in patients who exhibit signs and symptoms of bruxism. While most patients are not aware of bruxing activity, the presence of wear facets seen on the teeth or diagnostic casts alerts the dentist to the habit. It is estimated that about 5 percent of patients have wear severe enough to require restorative treatment.[19] These patients must be informed that they are bruxing, that they are causing destruction of tooth structure, and that no restorative material is available that is stronger than tooth structure. While some authorities believe perfection of the occlusion will stop bruxism, there is little evidence to support that belief.[20] Occlusal night guards should be fabricated for all bruxing patients, and they should be educated and convinced of the necessity of wearing these appliances at night (**Figure 5**).

Hard occlusal splints should be used as opposed to soft occlusal guards, as the latter have been demonstrated to increase EMG activity of the masseter muscles.[21] Occlusal splints may or may not decrease bruxism, but they do improve distribution of the forces of bruxism, and they do protect the teeth and restorations. The importance of patient education and motivation cannot be overstressed in this area, as it is clear that the finest night guard cannot function if it is not worn.

It is clear the dentist has the ethical obligation to complete restorative therapy that is within the standard of care. However, even the finest restorative dentistry will fail in a short time in the absence of proper oral hygiene and regular professional dental maintenance. Similarly, well-done restorations may mechanically fail in a bruxing patient who fails to wear an occlusal night guard. These patient factors are by and large out of the treating dentist's control, but it is likely a positive dentist/patient relationship could have a positive effect with compliance.

Tooth Factors

One factor that has not received adequate attention related to determination of the prognosis or longevity of a restoration is the nature of the tooth receiving the restoration. The position of the tooth in the arch can have an effect on the prognosis. Patients can generate significantly more bite force on the teeth most distal in the arch than they can on teeth with a more anterior position, and this may reduce the prognosis in some situations. All-ceramic crowns on molars fail at a seven times' higher failure rate than those on anterior teeth.[22] Given that most second molars are not visible at conversational

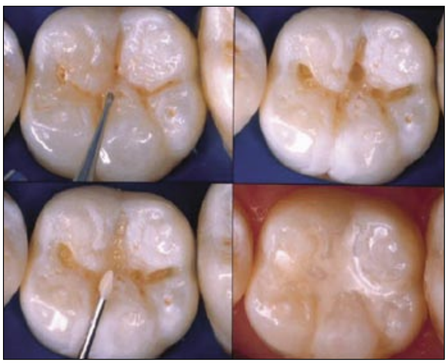


Figure 6. Preventive resin restorations are an excellent example of minimally invasive dentistry. *(Photo courtesy of Dr. R.J. Simonsen)*

Figure 7. Silver amalgam restorations have served the profession well but require more extensive loss of tooth structure than preventive resin restorations. *(Photo courtesy of Dr. R. Kahn)*

Figure 8. The slot preparation in conjunction with an occlusal sealant is a more conservative preparation than a traditional Class II preparation. *(Photo courtesy of Dr. R. Leung)*

Figure 9. This bonded ceramic onlay is a more conservative restoration than a porcelain-fused-to-metal crown.

distance, the wisdom and necessity of placing an all-ceramic restoration on those teeth must be questioned.

The occlusal stress to which abutment teeth will be subjected can also influence the prognosis. Abutment teeth for long-span posterior fixed partial dentures are at greater risk than teeth supporting single-unit crowns. Teeth used as abutments for cantilevered restorations are at significant risk, especially if they are endodontically treated.[23,24] Interestingly, teeth with poor periodontal support survive better than those with good support when used as abutments for cantilevered prostheses.[25,26] This seems to be because patients with reduced periodontal support produce substantially less bite force. It has also been shown that endodontically treated teeth are often subjected to excess biting force because of the absence of intrapulpal receptors that limit the amount of force a patient will generate.[27] Studies also indicate that the prognosis for a fixed restoration decreases when a combination of risk factors occurs.[28] These factors may include endodontically treated abutments, long occlusal spans, an active bruxing habit, etc.

One critical factor when determining a prospective prognosis for any given tooth is the amount of remaining tooth structure.[29-32] The words "preservation of tooth structure" which are uttered in almost all lectures related to tooth preparations, are critical to establishing a positive long-term prognosis. The amount of tooth structure removed from a tooth when preparing a porcelain laminate veneer is much less than when preparing a full crown.[33] Thus, the long-term prognosis for the veneered tooth is substantially better than that for the crowned tooth.

The advent of predictable adhesion to tooth structure has allowed clinicians the ability to practice minimally invasive dentistry, and thus preserve tooth structure and concomitantly improve the long-term prognosis of the tooth/ restoration complex. A preventive resin restoration in a mandibular first molar is more conservative than a minimal silver amalgam restoration improving the long-term prognosis for the tooth (**Figure 6**). A mesial slot preparation restored with adhesives and composite resin is more conservative than a Class II MO silver amalgam restoration, and cuspal flexibility is reduced with the slot preparation, thereby reducing the likelihood of cusp fracture over time (**Figures 7 and 8**). A bonded ceramic onlay conserves substantially more tooth structure than a traditional porcelain-fused-to-metal crown (**Figure 9**). While the bonded ceramic may or may not survive as long as a PFM crown, when it does fail, there is generally a considerable amount of tooth structure remaining. Conversely, while the crown restoration may survive longer initially, when it eventually fails, the failure is often catastrophic.

Clinicians are often faced with a difficult decision whether to retain a tooth that may require extensive therapy (endodontics, build up, orthodontic extrusion, periodontal therapy, full-crown preparation) or to extract the tooth and replace it with an osseointegrated implant. The success rates and excellent prognoses for implant-supported restorations are uniformly high compared to those for teeth requiring multiple procedures for restoration.[34] Implants have quietly become the method of choice when restoring missing teeth, and are being used more and more in favor of restoring teeth with a guarded prognosis.

Dental Laboratory Factors

Indirect restorations are fabricated in the dental laboratory, and survival rates of the restorations depend on the dentist's preparation and impression, the materials used in fabrication, and upon the knowledge, ability and skill of the laboratory technician. Experts have advocated for years that with PFM restorations, a full contour wax-up be made and "cut back" in a controlled fashion prior to casting. This will provide optimum support for the porcelain with the metal coping, result in a uniform thickness of porcelain, which will result in minimal stress at the porcelain/metal bond, and will also result in optimum esthetics. Assuming quality alloys are used, this approach can reduce the incidence of porcelain fracture to almost zero. Yet, this approach is rarely used in commercial laboratories, resulting in a higher than necessary incidence of porcelain fracture.

As was discussed with dentists, all laboratory technicians are not alike and their abilities probably would be distributed in a bell curve. The responsibility for ensuring that quality laboratory work is routinely obtained remains with the dentist. Based on the substantial amount of porcelain-fused-to-metal restorations that are currently fabricated using base metal and offshore laboratories, it would appear that many clinicians are choosing laboratories more on the basis of price than quality, and that this will probably be reflected in lower survival rates.

Discussion

Numerous studies have been carried out over the past 30 years to attempt to determine how long a restoration should last. Unfortunately, these studies do not provide clear, unambiguous guidelines to assist clinicians in giving their patients a reasonable prognosis for anticipated therapy. This is primarily because there are so many related and unrelated variables that factor into the actual result.

Some authorities flippantly state that insurance companies will replace a fixed-partial denture or crown after five years, so that should be our goal and determine the warranty provided. This type of thinking is irresponsible, irritating, irrelevant, and incorrect. Many studies indicate that fixed-partial dentures demonstrate about a 5 percent failure rate at 10 years. (Personal communication, Dr. Maxwell Anderson, RV Tucker Symposium, University of British Columbia, Vancouver, B.C., October 2005.) The real truth of the matter is that the survival rate of restorations depends on several factors, including the choice of material, quality of the service rendered by the dentist and technician, the amount of tooth structure remaining, the presence or absence of parafunctional habits, oral hygiene, diet, and others.

When dealing with biological and mechanical variables, the clinician should be cautious about making guarantees, and should instead give the patient a range of expected outcomes and explain that these are only guidelines.

Summary and Conclusions

Patients deserve and want to know what a reasonable expected outcome might be for proposed restorative therapy. Dentists must educate patients and help guide their decision making, but in the end, the decision belongs to the patient. While there is little "black and white" information regarding the expected prognosis, some conclusions can be drawn.

- There is no "best" material. All materials have indications and contraindications. Some possess low levels of technique sensitivity and others high levels.
- With materials with high levels of technique sensitivity, the knowledge and skill of the dentist are critical in achieving the desired result.
- Not all dentists and laboratory clinicians are equal.
- Patient factors including those of diet and hygiene are important to long-term survival, as are factors related to saliva and systemic health.
- Restorations placed in patients who suffer from nocturnal bruxism are at risk of mechanical failure. Mandatory use of a night guard is required.
- The amount of remaining tooth structure plays a major role in determining the prognosis. Minimally invasive adhesive restorative dentistry can assist in the preservation of tooth structure.
- The answer to the question, "How long will it last"? should be "It depends." CDA

References / 1. Walton, JN, Gardner FM, Agar JR, A survey of crown and fixed-partial denture failures: length of service and reasons for replacement. *J Prosthet Dent* 56:416, 1986.

2. Schwartz NL, Whitsett, LD, et al, Unserviceable crowns and fixed-partial dentures: lifespan and causes for loss of serviceability. *J Amer Dent Assoc* 81:1395, 1970.

3. Jendresen MD, Dental cements: reactor response. *Adv Dent Res* 1988; 2:146, 1988

4. Schwartz ML, Dental cements: reactor response. *Adv Dent Res* 2:142, 1988.

5. Smith, DC, Dental cements. *Adv Dent Res* 2:134, 1988.

6. Anusavice KA, Criteria for the selection of dental materials: properties versus technique sensitivity. In "Quality evaluation of dental materials" Quintessence Publishing Co., Chicago, 1989.

7. Leinfelder K, The enigma of dental amalgam. *J Esthet Rest Dent* 16:3, 2004.

8. Manhart J, Chen H, et al, Buonocore memorial lecture: review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. *Oper Dent* 29:481, 2004.

9. Donovan TE, Simonsen RV, et al, Retrospective clinical evaluation of 1,314 cast gold restorations in service from 1 to 52 years. *J Esthet Rest Dent* 16:194, 2004.

10. Studer SP, Wettstein F, et al, Long-term survival estimates of cast gold inlays and onlays with their analysis of failures. *J Oral Rehabil* 27:461, 2000.

11. Stoll R, Sieweke M, et al, Longevity of cast gold inlays and partial crowns: a retrospective study at a dental school clinic. *Clin Oral Invest* 3:100, 1999.

12. Mjor IA, Medina JE, Reasons for placement, replacement, and age of gold restorations in selected practices. *Oper Dent* 18:82, 1993.

13. Bentley C, Drake CW, Longevity of restorations in a dental school clinic. *J Dent Educ* 50:594, 1986.

14. Crabb H, The survival of dental restorations in a teaching hospital. *Brit Dent J* 150:315, 1981.

15. Wood, MR, Vermilyea SG, A review of selected dental literature on evidence-based treatment planning for dental implants: report of the Committee on Research in Fixed Prosthodontics of the Academy of Fixed Prosthodontics. *J Prosthet Dent* 92:447, 2004.

16. Seligman DA, Pullinger AG, Solberg WK, The prevalence of dental attrition and its association with factors of age, gender, occlusion, and TMJ symptomatology. *J Dent Res* 67:1333, 1988.

17. Thompson BA, Blount BW, Krumholz TS, Treatment approaches to bruxism. *Amer Fam Phys* 49:1617-22, 1994,

18. Graf H, Bruxism. *Dent Clin N Amer* 13:659, 1969.

19. Rugh JD, Harlan J, Nocturnal bruxism and temporomandibular disorders. *Advances in Neurology* 49:329, 1988.

20. Dawson Peter, Bruxism, In Evaluation, Diagnosis, and Treatment of Occlusal Problems: second edition: C.V. Mosby Co., 457.

21. Okeson JP, Phillips BA, et al, Nocturnal bruxing events: a report of normative data and cardiovascular response. *J Oral Rehabil* 623, 1994.

22. Goodacre CJ, Bernal G, et al, Clinical complications in fixed prosthodontics. *J Prosthet Dent* 90:31, 2003.

23. Karlsson S, Failures and length of service in fixed prosthodontics after long-term function. A longitudinal clinical study. *Swed Dent J* 13:185, 1989.

24. Lundgren D, Prosthetic reconstruction of dentitions seriously compromised by periodontal disease. *J Clin Periodontol* 18:390, 1991.

25. Laurell L, Lundgren D, Periodontal ligament areas and occlusal forces in dentitions restored with cross-arch unilateral posterior two-unit cantilever bridges. *J Clin Periodontol* 13:33, 1986.

26. Glantz PO, Nyman S, et al, On functional strain in fixed mandibular reconstructions. II: an in vivo study. *Acta Odontol Scand* 42:269, 1984.

27. Randow K, Glantz PO, Zoger B, Technical failures and some related clinical complications in extensive fixed prosthodontics. An epidemiological study of long-term clinical quality. *Acta Odontol Scand* 44:241, 1986.

28. Palmqvist S, Soderfeldt B, Multivariate analyses of factors influencing the longevity of fixed-partial dentures, retainers, and abutments. *J Prosthet Dent* 71:245, 1994.

29. Sorensen JA, Preservation of tooth structure. *J Calif Dent Assoc* 16(11):15-22, 1988.

30. Donovan TE, Chee WWL, Endodontically treated teeth: a summary of restorative concerns. *J Calif Dent Assoc* 21(12):49-56, 1993.

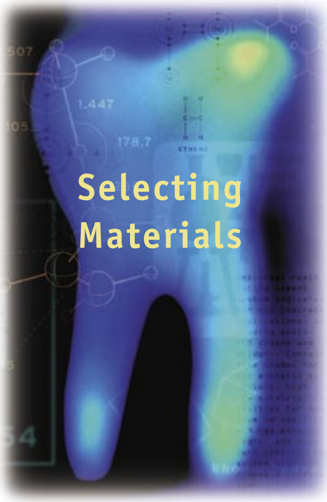
31. Panitvisai P, Messer HH, Cuspal deflection in relation to restorative and endodontic procedures. *J Endo* 21:57, 1995.

32. Sorensen JA, Martinoff JT, Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. *J Prosthet Dent* 51:780, 1984.

33. Edelhoff D, Sorensen JA, Tooth structure removal associated with various preparation designs for anterior teeth. *J Prosthet Dent* 87:503, 2002.

34. Cho GC, Evidence-based approach for treatment planning options for the extensively damaged dentition. *J Calif Dent Assoc* 32(12):983-90, 2004

To request a printed copy of this article, please contact / Terry E. Donovan, DDS, University of Southern California School of Dentistry, Room 4366, University Park MC 0641, Los Angeles, Calif., 90089.



The Selection of Contemporary Restorative Materials: Anecdote vs. Evidence-Based?

Terry E. Donovan, DDS

Abstract

The contemporary practitioner is faced with a bewildering number of options from which to choose when selecting restorative materials. There are not only many different types of materials available, but also numerous options for any given group of materials. For example, many manufacturers offer their customers three or even four different dentin bonding agents. The sheer number of available products is in itself overwhelming. When coupled with aggressive marketing strategies, misinformation supplied by paid clinicians at many seminars and lectures, and infomercials disguised as scientific articles in many of the trade journals, it is little wonder that the average ethical practitioner is frustrated when attempting to make rational choices.

Clinicians use information gleaned from a variety of sources to make these difficult decisions. This article will attempt to evaluate the validity of these sources and will provide a philosophical matrix to assist the practitioner in making rational decisions relative to materials selection.

One of the parameters that is frequently used to differentiate materials from one another is in vitro data related to their physical properties. It is imperative clinicians understand that differences between material in terms of physical properties are very poor predictors of clinical performance.[1-3] Substantial improvements in physical properties do not necessarily translate into improvements of clinical performance. For example, existing hybrid composite resin materials have adequate compressive strength. A new material with three times that compressive strength will not perform better clinically, because existing materials already exceed the critical threshold for this parameter.

It is very fashionable today to demand that dental professionals practice "evidence-based" dentistry. While this principle is clearly important, it is also critical to understand that very little of what oral health care providers do clinically has a solid, unam-

Guest editor / Terry E. Donovan, DDS, is professor and director, Advanced Education in Prosthodontics, and co-chairman, Division IV, Primary Oral Health Care, University of Southern California School of Dentistry.

biguous evidence base supporting it. The epitome of "evidence-based" is a meta-analysis of prospective randomized controlled clinical trials. Very few properly constructed clinical trials have been conducted, which precludes the existence of acceptable meta-analyses. Thus, accessing an "evidence-base" is neither simple nor straightforward.

However, "evidence" does exist and is available. It does require that knowledgeable "experts" gather and synthesize information from a variety of sources, and then disseminate that information in a responsible manner to practicing dentists. This process specifies significant professional and ethical responsibilities for both the "expert" and the practitioner who is the consumer of the information.[4] Both the expert and the consumer must recognize the potential for selective bias when referencing studies to support a specific material or technique.[5] Both must also be responsible for critically evaluating the scientific validity of referenced studies.

Sources of Information

There are numerous potential sources from which a clinician can gain information that contributes to the evidence-base supporting or refuting use of a material or technique. It is important that practitioners understand that the power or validity of the information varies considerably with the source. At the top of the list are prospective clinical trials published in peer-reviewed journals.[6] These studies are evaluated by an editor-in-chief, a section editor, and then by two or more "experts" in the discipline. These experts have a reasonable, but not automatic, chance at identifying deficiencies in the experimental method or statistical analysis. As a result, many articles describing many deficient studies are rejected and do not become part of the recorded literature. However, many studies that have significant deficiencies do get published. Frequently, the conclusions reached in these articles are not supported by the data. Often these inaccurate conclusions are quoted by other authors, and the misconceptions are perpetuated. The intelligent clinician must understand that just because something is in the literature, it doesn't necessarily mean it is correct.

Thus, the contemporary clinician, by necessity, must be a critical consumer of the literature, and indeed of any information received from all sources.

Very few properly constructed clinical trials have been conducted, which precludes the existence of acceptable meta-analyses.

In this regard, it is important to realize that practitioners in the real world have multiple roles to play. They must manage a significant small business, supervise a diverse staff of auxiliaries, keep up with changes in materials and techniques, and also maintain a semblance of a normal life. It is difficult, if not impossible, for the average practitioner to juggle all of these responsibilities, and thus, it is unrealistic to expect them to keep up with the peer-reviewed literature on a meaningful basis. This places increased responsibility on "experts" to supply factual, well-supported information to clinicians.

A lower level of validity is assigned to in vitro laboratory studies. As mentioned earlier, studies evaluating basic physical properties of materials are not particularly useful in predicting clinical performance. (Personal communication, Dr. J. Robert Kelly, American Academy of Restorative Dentistry, 2002.) In vitro laboratory studies evaluating parameters such as marginal integrity, bond strengths, etc. can provide important information and evidence, but these should eventually be supported by corroborating clinical evidence.

An important factor in evaluating the relative validity of an in vitro study is the mode of testing. Most clinical failures that are not a result of recurrent caries are mechanical failures due to fatigue of either the restorative material or the tooth/restoration complex. Load-to-failure studies do not test either teeth or materials in the manner in which they fail, and thus have minimal validity and provide little valuable information to clinicians. Fatigue studies come much closer to mimicking intraoral conditions. Such studies are clearly more difficult to carry out, but have considerably more predictive value. These studies also must be carefully scrutinized to ascertain that meaningful forces were used, and that additional procedures such as thermocycling, etc. were carried out.

Another type of article that is frequently cited as "evidence" is a review article. These articles can be of considerable value in terms of quickly learning what is known about a given material at a specific point. However, often review articles suffer from an inherent bias that may be held by the author(s), and the reader should be aware of such deficiencies. Case studies and case reports may describe a new technique or reveal useful clinical tips, but are considered relatively light on the evidence scale.

The alternative sources of information have relative levels of validity. Trade journals and tabloids generally publish biased infomercials, often with full-page advertisements for the material described in the article appearing within the body of the article.

Newsletters can provide information on handling characteristics of a product, packaging details, accuracy of shades, etc., but generally have minimal scientific validity. The Internet is a source of information, but unfortunately, bad information seems to be more readily available than good information. One site that has proven invaluable in the past few years is the U.S. Air Force Dental Investigation Service, (http://www.brooks.af.mil/dis/).[7] This is a free, unbiased site that provides excellent information on new products in a timely manner.

The Role of Postdoctoral Continuing Dental Education

Most clinicians obtain a majority of their information on new products by attending various types of continuing education programs. These include dental society meetings, university-sponsored courses, study clubs, private institutional programs, symposia, and a host of electronic alternatives. The truth is, these courses and programs vary widely in their validity and content. Again, the clinician must be a critical consumer of continuing dental education, and must hold presenters responsible for providing scientific documentation to support their statements. Lecturers must properly disclose financial relations related to any of the products they are recommending. The increasing tendency for local societies to request funding from manufacturers and suppliers for their scientific meetings has the potential to reduce the program to infomercial status due to speaker bias.

One benefit of mandatory continuing dental education is the fact that previously isolated practitioners get to communicate with each other. Never underestimate information that is received from respected colleagues. In this regard, the optimum continuing education program is an ongoing study club where practitioners with a specific interest get together on a regular basis for a prolonged period. Peer learning in these situations can be very powerful. Critical evaluation of one's own successes and failures is also a valuable tool.

Finally, some materials have simply passed the test of time, and even though they have never been the subject of valid clinical trials, they are considered to be "acceptable" because they have a long history of use. Zinc phosphate cement is a classic example. There have been many in vitro laboratory studies published related to zinc phosphate cement, but almost no valid clinical trials. Yet, it has been used successfully for more than 100 years, and is considered the gold standard to which all other cements are compared.[8]

The clinician must be a critical consumer of continuing dental education, and must hold presenters responsible for providing scientific documentation to support their statements.

Technique Sensitivity of Dental Materials

One critical factor in deciding whether or not to use a specific material is its relative level of "technique sensitivity."[9] A material can be described as technique-sensitive when different clinicians achieve significantly different results when using it. Silver amalgam is a material with very low technique sensitivity because clinically acceptable results can be achieved by almost all operators.[10] Placing composite resin restorations in posterior teeth can be described as technique-sensitive due to inherent difficulties in isolation, selection and manipulation of bonding agents, and factors related to controlling polymerization shrinkage stresses. Because of these variables, different clinicians achieve very different results with the resulting restoration. Cast gold is also a technique-sensitive material.[11] Clinical trials of cast gold have demonstrated equivocal results.[12-16] The difference in the results of these trials is likely a result of variability in the ability of the operators.

A rule of thumb that should be considered when selecting materials is that materials that are considered technique-sensitive should only be used where there is a well-defined advantage to be derived from using them. For example, glass ionomer cement is considered by some authorities to be more technique-sensitive than zinc phosphate cement. The primary advantage of glass ionomer is fluoride release that **might** provide some protection against recurrent caries. It would be rational to use glass ionomer cement to cement castings in a patient who is caries-prone, but probably not rational to use it in a patient who is relatively resistant to dental caries. Thus, another useful principle to be considered when selecting a dental material is that unless there are specific indications for a specific product, the least technique-sensitive material should be utilized.

Product Packaging

A final consideration that is used when selecting a product is the packaging of the product. In situations where multiple products have similar utility, one product may be selected because the clinician prefers the packaging of that product. Many practitioners prefer a uni-dose approach and thus may select one brand of composite resin over another because it is available in uni-dose and the other isn't. Some dental cements are supplied with a dispenser that extrudes equal amounts of base/catalyst, which simplifies the mixing procedure and permits dispensing variable amounts of cement so that simultaneous cementation of multiple casting is possible if desired. Some cements are supplied in a precapsulated auto-mix form which may be preferred by some dentists. Similarly, a clinician may well select an impression material because it is available with an auto-mix system.

The preceding discussion described the basic information base that may be utilized to select restorative materials. The following examples will illustrate a thought process used for the selection of dental cements and composite resins.

Dental Cements and Luting Agents

There are many different dental cements available to the clinician. Literally, hundreds of articles have been written on this subject and countless studies have been described in the literature. A relatively small number of studies have been properly conducted clinical trials, so the clinician must synthesize information from various sources when considering product choices.

Laboratory studies related to apparently important physical properties provide little illumination to the clinician. There are differences between available cements in terms of compressive strength, diametral tensile strength, adhesion the tooth structure, solubility, film thickness, etc., but there is no evidence improvements in any of these physical properties results in improved clinical performance.[17-21]

Clinical studies have been conducted comparing solubility and postcementation sensitivity with different cements.[22-25] While differences in solubility are apparent, it does not seem that they are clinically significant with restorations possessing acceptable fit, nor does it appear that the improvements in solubility can compensate for poor fit. It also appears that the postcementation sensitivity anecdotally reported with both zinc phosphate cement and glass ionomer cement is operator-related and can be prevented with proper technique.[26-32]

Thus, it seems that the major determining factors in selecting a dental cement are a history of successful use and relative differences in technique-sensitivity. Both zinc phosphate and resin-modified glass ionomer cements have a long history of successful clinical use, are relatively easy to manipulate, and lack significant technique sensitivity. Conventional glass ionomer cements have certainly been used successfully, but are considered by some to be more technique-sensitive than zinc phosphate or resin-modified glass ionomers. It seems reasonable to recommend that metal restorations, including cast gold and porcelain-fused-to-metal crowns be cemented with either zinc phosphate or resin-modified glass ionomer cement. The choice between these two groups of materials can essentially be based on operator preference. In that regard, contemporary dispensing systems have made the resin-modified glass ionomer materials very easy to use and hence they have become extremely popular.

> The clinician must synthesize information from various sources when considering product choices.

Resin cements are generally more technique-sensitive than conventional cements and resin-modified glass ionomer cements. Important variables with these cements include maintenance of a dry field, working times, ultimate film thickness, flow of the cement and removal of excess cement. These cements should be utilized only in specific clinical situations where the benefits accruing from use of the cement warrant the risk entailed. These situations include the cementation of Maryland fixed-partial dentures, etchable all-ceramic crowns, ceramic or composite inlays and onlays, and laminate veneers.

Composite Resin Restorative Materials

Composite resin restorative materials have been available for close to 50 years. These materials, when bonded to tooth structure with the appropriate adhesives, have made the concept of minimally invasive dentistry a reality. The literature related to composite resins is voluminous, as they have been extensively evaluated in both laboratory and clinical studies. Studies comparing physical properties of composite resin materials do little to assist the clinician in making an appropriate selection. However, such studies have determined that micro-filled composite materials have a low elastic modulus. This limits their use in stress-bearing situations (posterior teeth, Class IV restorations), but makes them the material of choice for the restoration of abfraction lesions. Many believe such lesions are at least in part caused by tooth flexure, and a low modulus material seems to perform better than a more rigid material in those situations.[33-41]

Studies evaluating flowable composites have demonstrated that these materials have generally poor physical properties and excessive polymerization shrinkage. The physical properties and shrinkage vary considerably from material to material, and the differences are related to the wide range of filler content of these products. This combination of poor strength and wear resistance, coupled with high shrinkage would seem to restrict the use of flowables. The primary use for a flowable composite resin would be as a lining material with posterior composite restorations.

Clinical trials with posterior composite resin materials have established that materials with a high filler content using small filler particles will perform well in small to intermediate cavity preparations. Wear of such materials ranges from six to 15 microns per year and most modern hybrid composite resins demonstrate substantially equivalent performance. Trends in recent years have tended toward the development of hybrid composites that are highly filled (> 75 percent) with filler particles that are getting smaller and smaller.

Recently a nano-filled composite resin material (Filtek Supreme Plus, 3-M/ESPE, St. Paul, Minn.) was introduced into the North American market. This material has a high filler content of very small filler particles. The material polishes very easily, resulting in excellent esthetics, and it is expected to display excellent wear resistance. It has a slightly lower elastic modulus than traditional hybrid composites, and this raises two important questions. Is the modulus low enough to recommend use of the material in abfraction lesions? Will the lower elastic modulus have a negative effect on clinical performance for posterior restorations? Laboratory studies cannot provide answers to these questions. It is simply not known what the threshold is, positive and negative, relative to the elastic modulus. The answers can only come from data generated in clinical trials.

Because modern hybrid composites display equivalent performance, choice of materials is based on operator preference. Factors that might be important in this regard include handling characteristics, availability of shades, packaging or even price. With these materials, manipulation is far more critical than material selection. Critical manipulative variables include obtaining adequate isolation, proper etching of the enamel and dentin hybridization, incremental placement of the composite material, and proper finishing techniques. Techniques to reduce or minimize stress at the bonded dentin surface should be considered. These include use of a thin liner (0.5 mm.) of flowable composite, use of a resin-modified glass ionomer liner, use of a soft-start polymerization technique, and incremental build-up or sectioning techniques to reduce the "c-factor" effect inherent with certain cavity preparations.

Table 1

Matrix for introduction of new materials

- Wait for independent clinical evidence.
- Ask the "experts."
- Understand the materials or system.
- Practice with the material prior to using it with patients.
- Proceed with caution.

Summary

In summary, materials selection in restorative dentistry has become increasingly complex. Clearly, it is desirable that "evidence-based" dentistry is practiced, but clear, unambiguous evidence is not available for many materials. There is evidence available for most materials, but it must be synthesized from data from a variety of sources. It is likely unreasonable to expect the average practitioner to keep up with the peer-reviewed literature, so "experts" play a significant role in this regard. "Experts" have a responsibility to disclose financial affiliations and to present factual, unbiased presentations backed by what scientific evidence is available. Dentists have a responsibility to be critical consumers of continuing dental education, and are encouraged to get involved in a study club activity.

Ultimately, the responsibility for proper materials selection rests with the clinician. Practitioners must have the discipline to decline use of a material until there is clinical evidence to demonstrate its utility. For example, the new nano-composite material described above may well prove to be an improvement over traditional hybrids. However, there is a possibility that clinical performance could be inferior to that of hybrids. Because the hybrid materials have performed well for some period of time, clinicians would be wise to wait until at least short-term clinical data is available to support use of the new material.

The following "matrix" is included (see **Table 1**) to assist the practitioner in making choices related to newly introduced dental materials:

■ Wait for independent clinical evidence before using a new product. Sharer's criteria for all-ceramic restorations seem applicable to most materials.[42] He suggests that materials be tested for a minimum of three years, optimally five years, and have a success rate of 95 percent or better at these time frames. If the supplier cannot provide the evidence, be disinclined to try the product.

■ Ask "experts" in the discipline what their opinions and experiences are with the product. They have often had experiences with the product for substantial time periods prior to formal commercial instruction to the profession.

■ Before using the product, make certain you understand its composition, indications and contraindications and any critical manipulative variables. For example, many all-ceramic crowns require specific tooth preparation and cervical margin designs, as well as specific cementation protocols. Failure rates may be excessively high if these specific details are not followed.

■ Practice with material on extracted teeth prior to using it in a patient. Many materials have specific handling characteristics that should be known before using them in vivo.

■ Proceed with caution. Try the material in a few situations where it might clearly be indicated and critically evaluate the short-term results. Then try it in a situation where one might be "pushing the envelope" slightly, and again evaluate the results. When satisfied with these results, incorporate the material as indicated into the practice.

The choice of dental material to be used in any specific clinical situation will depend upon the complex interaction of a number of factors. The clinician must be responsible for understanding the nature of materials available, and must communicate the available choices to the patient so that informed consent may be given. Finally, the clinician must understand the critical manipulative variables with any specific material so that optimum performance of that material will result. CDA

References / 1. Jendresen MD, Dental cements: reactor response. *Adv Dent Res* 2:146, 1988.

2. Schwartz, ML, Dental cements: reactor response. *Adv Dent Res* 2:142, 1988.

3. Smith DC, Dental cements. *Adv Dent Res* 2:134, 1988.

4. Donovan TE, Promising indeed: The role of experts and practitioners in the introduction and use of new materials in restorative dentistry. *J Esthet Rest Dent* 16:331, 2004.

5. Bader JD, Be wary of experts citing evidence. *J Esthet Rest Dent* 16:207, 2004.

6. Jacob RF, Carr AB, Hierarchy of research design used to categorize the "strength of evidence" in answering clinical dental questions. *J Prosthet Dent* 83:137-52, 2000.

7. Heymann HO, U.S. Air Force Dental Investigation Service: a "hidden gem." *J Esthet Rest Dent* 17:1, 2005.

8. Donovan TE, Cho GC, A contemporary evaluation of dental cements. *Compendium* 20:197, 1999.

9. Anusavice KA, Criteria for the selection of dental materials: Properties versus technique sensitivity. In "Quality evaluation of dental materials" Quintessence Publishing Co., Chicago, 15:1989.

10. Leinfelder K; The enigma of dental amalgam. *J Esthet Rest Dent* 16:3, 2004.

11. Donovan TE, Simonsen RV, Geurtin G, Tucker RV, Retrospective clinical evaluation of 1,314 cast gold restorations in service from 1 to 52 years. *J Esthet Rest Dent* 16:194, 2004.

12. Studer SP, Wettstein F, et al, Long-term survival estimates of cast gold inlays and onlays with their analysis of failures. *J Oral Rehabil* 27:461, 2000.

13. Stoll R, Sieweke M, et al, Longevity of cast gold inlays and partial crowns: A retrospective study at a dental school clinic. *Clin Oral Invest* 3:100, 1999.

14. Mjor IA, Medina JE, Reasons for placement, replacement, and age of gold restorations in selected practices. *Oper Dent* 18:82, 1993.

15. Bentley C, Drake CW, Longevity of restorations in a dental school clinic. *J Dent Educ* 50:594, 1986.

16. Crabb H, The survival of dental restorations in a teaching hospital. *Brit Dent J* 150:315, 1981.

17. White SN, Sorensen JA, Kang SK, Microleakage of new crown and fixed partial denture luting agents. *J Prosthet Dent* 67:156, 1992.

18. White SN, Yu Z, et al, In vivo microleakage of luting cements for cast crowns. *J Prosthet Dent* 71:333, 1994.

19. Kydd WL, Nicholls JI, Harrington G, Marginal leakage of cast gold crowns luted with zinc phosphate cement. *J Prosthet Dent* 75:9, 1996.

20. White SN, Yu Z, Physical properties of fixed prosthodontic, resin composite luting agents. *Int J Prosthodont* 6:248, 1993.

21. White SN, Yu Z, Compressive and diametral strength of current adhesive luting agents. *J Prosthet Dent* 69:568, 1993.

22. Wilson AD, Specification test for solubility and disintegration of dental cements: A critical evaluation of its meaning. *J Dent Res* 55:721, 1976.

23. Osborne JW, Swartz ML, et al, A method for assessing the clinical solubility and disintegration of luting agents. *J Prosthet Dent* 40:413, 1978.

24. Mitchem JC, Gronas DG, Clinical evaluation of cement solubility. *J Prosthet Dent* 40:453, 1978.

25. Mitchem JC, Gronas DG, Continued evaluation of clinical solubility of dental cements. *J Prosthet Dent* 45:289, 1981.

26. Wozniak W, Reported sensitivity to glass ionomer luting cements. *J Am Dent Assoc* 109:476, 1984.

27. Berry EA, Berry EL, The successful use of glass ionomer luting cements without postcementation sensitivity. *Texas Dent J* 104:8, 1987.

28. Johnson GH, Powell LV, Derouen TA, Evaluation and control of post-cementation pulpal sensitivity: Zinc phosphate and glass ionomer luting cements. *J Am Dent Assoc* 124:39, 1993.

29. Bebermeyer RD, Berg JH, Comparison of patient-perceived post-cementation sensitivity with glass ionomer and zinc phosphate cements. *Quintessence Int* 25:209, 1994.

30. Kern M, Kleimeier B, et al, Clinical comparison of postoperative sensitivity for a glass ionomer and a zinc phosphate luting cement. *J Prosthet Dent* 75:159, 1996.

31. Brackett WW, Metz JE, Performance of a glass ionomer cement over five years in a general practice. *J Prosthet Dent* 1992; 67:59, 1992.

32. Metz JE, Brackett WW, Performance of a glass ionomer cement over eight years in a general practice. *J Prosthet Dent* 1994; 71:13, 1994.

33. Lee WC, Eakle WS, Possible role of tensile stress in the etiology of cervical erosive lesions of teeth. *J Prosthet Dent* 1984; 52:374, 1984.

34. Lee WC, Eakle WS, Stress-induced cervical lesions: review of advances in the past 10 years. *J Prosthet Dent* 75:487, 1996.

35. Grippo JO, Noncarious cervical lesions: The decision to ignore or restore. *J Esthet Dent* 4:55, 1992.

36. Heymann HO, Sturdevant JR, et al: Examining tooth flexure effects. *J Amer Dent Assoc* 122:41, 1991.

37. Leinfelder KF, Restoration of abfracted lesions. *Comp Cont Dent Ed* 15:1396, 1994.

38. Powell LV, Johnson GH, Gordon GE, Factors associated with clinical success of cervical abrasion/erosion restorations. *Oper Dent* 20:7, 1995.

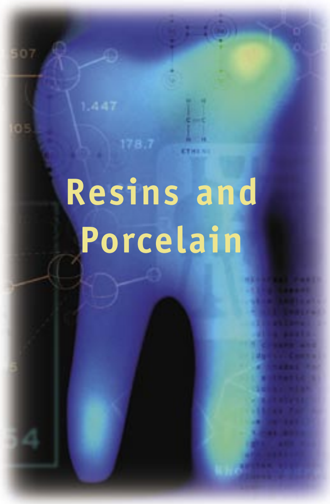
39. Levitch LC, Bader JD, et al, Noncarious cervical lesions. *J Dent* 22:195, 1994.

40. Bader JD, McClure F, et al, Case-control study of non-carious cervical lesions. *Community Dent Oral Epidemiol* 24:286-91, 1996.

41. American Academy of Operative Dentistry: Noncarious cervical lesions. Recommendations for clinical practice. *Oper Dent* 28:109-113, 2003.

42. Scharer P, All-ceramic crown systems: Clinical research versus observation in supporting claims. *Signature* 4(3 Suppl):1, 1997.

To request a printed copy of this article, please contact / Terry E. Donovan, DDS, University of Southern California School of Dentistry, Room 4366, University Park MC 0641, Los Angeles, Calif., 90089.



Composite Resins and Bonded Porcelain: The Postamalgam Era?

Pascal Magne, DMD, PhD

Abstract

The growing demand of patients for esthetic or metal-free restorations, together with the ongoing interest of the dental profession for tissue-preserving materials have led to the actual development of posterior adhesive restorations. It is now clearly established that a new biomimetic approach to restorative dentistry is possible through the structured use of "tooth-like" restorative materials (composite resins and porcelain) and the generation of a hard tissue bond (enamel and dentin bonding). Scientific studies and clinical experience have validated use of bonded tooth-colored restorations, and we may have entered the so-called "postamalgam era."

These significant changes have already impacted daily general practice, including pediatric dentists in California, but it is now critical to assure that the corresponding evidence-based process is integrated to the predoctoral programs statewide and nationwide. This paper reviews the foundations of this evolution, based on maximum tissue preservation and sound biomechanics, the so-called "biomimetic principle." Using scientific evidence and clinical experience, a model for the adequate use of current restorative systems is presented. This work, illustrated with cases with up to 10 and 14 years' follow-up, sets the ground rules for the clinical performance of the posterior esthetic restoration. Important considerations about tooth preparation, matrix techniques, layering methods, immediate dentin sealing and base lining are presented.

It is common knowledge that patients' requests and clinicians' interest in esthetic restorations are not limited to anterior teeth. As a result, posterior tooth-colored adhesive restorative techniques have grown considerably over the last decade. It was clearly established that a new biomimetic approach to restorative dentistry was possible through the structured use of "tooth-like" restorative materials (composite resins and porcelain) and the generation of a hard tissue bond (enamel and dentin bonding).[1] Scientific studies and clinical experience have validated use of bonded tooth-colored restorations (see Section 3.) and we may have entered the so-called postamalgam era.[2] The changes toward esthetic and adhesive dentistry have largely impacted daily clinical practice,

Author / Pascal Magne, DMD, PhD, is associate professor with tenure, chair of Esthetic Dentistry, Division of Primary Oral Health Care, University of Southern California School of Dentistry.

Acknowledgments / The author wishes to express gratitude to the Faculty Esthetic Update group, Drs. T. Donovan, G. Harmatz, S. Jivraj, R. Kahn, B. Keselbrenner, T. Kim, R. Leung, C.R. Philips, C. Shuler, as well as dental technologists M. Magne and D. Cascione, Division of Primary Oral Health Care, USC School of Dentistry for helpful contribution and discussions during the evidence-based revision of the curriculum at USC School of Dentistry. Special thanks to Dr. Donovan for the review of the English draft.

and it is now critical to assure that the corresponding evidence-based process is integrated to the predoctoral programs statewide and nationwide. Educators, both in the academic arena and in the lecture circuit, hold the responsibility to provide the most contemporary oral health care level in restorative dentistry based on maximum tissue preservation and sound biomechanical principles. It will be explained why these goals cannot be achieved with traditional materials and techniques. A number of European schools have abandoned the teaching of amalgam or are in the process of achieving that goal.[3,4] Pediatric dentistry is not excluded from this phenomenon.[5] There are numerous reasons for this change.

From an academic perspective, shifting from amalgam to tooth-colored materials in teaching the restoration of posterior teeth may be found to have a considerable enriching effect on the dental curriculum, mainly due to tissue preservation and the biomechanical principles that will be discussed in Section 1.[3] As stated by Roeters et al., the introduction of resin composites is not just a change in materials and techniques but also a change in treatment philosophy.[4] The reduced need for preparation and the strengthening effect on the remaining tooth were the principal reasons for the shift from dental amalgam to adhesive dentistry with resin composite at Nijmegen dental school. The same philosophy inspired curricular changes in the dental schools at University of Zurich and Geneva, where this shift also started 20 and 15 years ago, respectively.

It can be questioned whether these changes will affect some specific area of restorative dentistry such as pediatric dentistry during community service to the underserved population, where amalgam is considered most adequate because of its simplicity of use. It appears that the benefits of adhesive tooth-colored materials apply also to primary molars, more conservative preparations can be performed maintaining more tooth structure.[6,7] Simplified adhesive protocols have also been proposed, as for instance the use of glass ionomer cements and in particular the resin-modified types, which possess properties that make them almost ideal for pediatric dentistry. Data indicates that resin-based composite and resin-modified glass ionomer serve very well in pediatric dentistry and are considered the material of choice by 40 percent of California pediatric dentists.[8,9]

As stated by Roeters et al., the introduction of resin composites is not just a change in materials and techniques but also a change in treatment philosophy.

The core material presented in this article is a summary of an evidence-based staged process taking place at the predoctoral level (section restorative dentistry) at the USC School of Dentistry. A small group of full-time faculty (Faculty Esthetic Update group) was created and led by the author to:

- Analyze the available literature,
- Develop a structured hands-on experience,
- Design and construct a manual for posterior esthetic restorations, and
- Calibrate the rest of the faculty based on these new curricular changes.

The article will review the data currently available to support the transition from the amalgam era to the new "biomimetic" era in restorative dentistry, and will also review data to help the clinician choose between composite resin and ceramics for posterior bonded restorations. Essential clinical steps to best use these two different materials will also be illustrated.

Section 1. Composite Resins and Ceramics According to the Biomimetic Principle

Biomimetics is a concept of medical research that involves the investigation of both structures and physical functions of biological "composites" and the designing of new and improved substitutes. In dental medicine, the term "biomimetics" is a useful word with increasing popularity. The primary meaning refers to material processing in a manner similar to the oral cavity such as the calcification of a soft tissue precursor. The secondary meaning of biomimetics refers to the mimicking or recovery of the biomechanics of the original tooth by the restoration. This of course is the goal of restorative dentistry. The benefit of biomimetics, when extended to a macrostructural level, can trigger innovative principles in restorative dentistry.

Restoring or mimicking the biomechanical, structural, and esthetic integrity of teeth constitutes the driving force of this process. Physiological performance of intact teeth is the result of an intimate and balanced relationship between biological, mechanical, functional, and esthetic parameters.[1]

Natural teeth, through the optimal combination of enamel and dentin, constitute the perfect and unmatched compromise between stiffness, strength, and resilience. Restorative procedures and alterations in the structural integrity of teeth can easily violate this subtle balance. Another alteration is represented by the age-related changes of the dentition, which constituted the main challenge

Table 1

Physical properties of dental hard tissues and corresponding biomaterials

	Elastic modulus (GPa)	Thermal expansion coefficient ($X10^{-6}/°C$)	Ultimate tensile strength (MPa)		Corresp. material	Elastic modulus	Thermal expansion coefficient	Ultimate tensile strength
Enamel	~80[1]	~17[2]	~10[3]	→	Feldspathic ceramics	~60-70[4]	~13-16[5]	~25-40[6]
Dentin	~14[7]	~11[2]	~44-105[7,8]	→	Hybrid composites	~10-20[9]	~20-40[10]	~40-60[11]

1. Craig RG, Peyton FA, Johnson DW, Compressive properties of enamel, dental cements, and gold. *J Dent Res* 40:936-45, 1961.

2. Xu HC, Liu WY, Wang T, Measurement of thermal expansion coefficient of human teeth. *Aust Dent J* 34:530-5, 1989.

3. Bowen RL, Rodriquez M, Tensile strength and modulus of elasticity of tooth structure and several restorative materials. *J Am Dent Assoc* 64:378-87, 1962.

4. Seghi RR, Denry I, Brajevic F, Effects of ion exchange on hardness and fracture toughness of dental ceramics. *Int J Prosthodont* 5:309-14, 1992.

5. Whitlock RP, Tesk JA, et al, Consideration of some factors influencing compatibility of dental porcelains and alloys. Part I. Thermo-physical properties. pages 273-82. In Proc. Fourth Int. Precious Metals Conference, Toronto, June 1980. Willowdale, Ontario: Pergamon Press Canada, April 1981.

6. Leone EF, Fairhurst CW, Bond strength and mechanical properties of dental porcelain enamels. *J Prosthet Dent* 18:155-9, 1967.

7. Sano H, Ciucchi B, et al, Tensile properties of mineralized and demineralized human and bovine dentin. *J Dent Res* 73:1205-11, 1994.

8. Staninec M, Marshall GW, et al, Ultimate tensile strength of dentin: evidence for a damage mechanics approach to dentin failure. *J Biomed Mater Res (Appl Biomater)* 63:342–5, 2002.

9. Willems G, Lambrechts P, et al, A classification of dental composites according to their morphological and mechanical characteristics. Dent Mater 8:310-9, 1992.

10. Versluis A, Douglas WH, Sakagushi RL, Thermal expansion coefficient of dental composites measured with strain gauges. *Dent Mater* 12:290-4, 1996.

11. Eldiwany M, Powers JM, George LA, Mechanical properties of direct and post-cured composites. *Am J Dent* 6:222-4, 1993.

of modern dentistry, facing a population that is clearly aging and at the same time, retaining more of its natural teeth. Restorative procedures and aging can make the tooth crown more deformable, and the tooth can be strengthened by increasing its resistance to crown deformation. When a more flexible material replaces the enamel shell, one can expect only partial recovery of crown rigidity. From a biomechanical perspective, composite resins are more "dentin-like" while porcelain is the most "enamel-like" material (**Table 1**).

The Biomimetic Principle in Restorative Dentistry

The intact tooth in its ideal hues and shades, and perhaps more importantly in its intracoronal anatomy, mechanics and location in the arch, is the guide to reconstruction and the determinant of success. The approach is basically conservative and biologically sound. This is in sharp contrast to the porcelain-fused-to-metal technique, in which the metal casting with its high elastic modulus makes the underlying dentin hypofunctional. The goal of biomimetics in restorative dentistry is to return all of the prepared dental tissues to full function by the creation of a hard tissue bond that allows functional stresses to pass through the tooth, drawing the entire crown into the final functional biologic and esthetic result. The goal of adhesive restorative techniques is the maximum preservation of sound tooth structure and the maintenance of the vitality of the teeth to be restored. From a biomechanics standpoint (**Table 1**), moderate alterations of teeth should be treated with composite resins. Bonded porcelain restorations are recommended to treat the most perilous situations (worn, non-vital, or fractured teeth) thus avoiding the use of intraradicular posts or full-coverage crowns. This results in considerable improvements, comprising both the medical-biological aspect and the socioeconomical context (i.e. decrease of costs when compared to traditional and more invasive prosthetic treatments).

Major advances have resulted from the study and understanding of cuspal flexure and plastic yielding, which represent key parameters in the performance of the tooth-restorative complex.[10,11] Subclinical cuspal micro-deformation, i.e. below the threshold of chairside observation, has been identified since the early 1980s by Morin et al.; and it is now well accepted that intact posterior

Figure 1. Typical crack developing under an existing MOD amalgam restoration due to the absence of cusp stabilization. There was no decay but significant pain to hot/cold air or fluids, and biting.

Figure 2a.

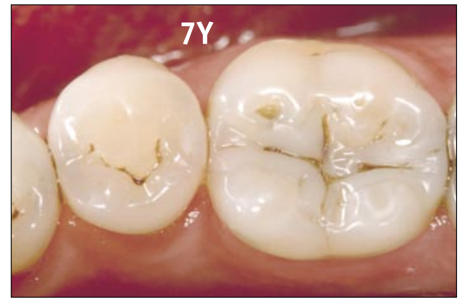


Figure 2b.

Figure 2c.

Figure 2d.

Figure 2. Examples of clinical follow-ups of OB direct composites at four years (a) and MOD at seven years (b), an OD intraoral composite inlay at 10 years (c), and an MOD extraoral semi-direct composite inlay at 14 years (d).

teeth demonstrate cuspal flexure due to their morphology and occlusion.[12,13] Restorative procedures can increase cuspal movement under occlusal load, which in turn may result in altered strength, fatigue fracture, and cracked tooth syndromes.[14-17] Amalgam restorations are the most typical example of this phenomenon (**Figure 1**). Such knowledge allowed considerable development of methods improving fracture resistance of teeth through various forms of full or partial coverage and, more recently, through the use of conservative adhesive techniques (**Figure 2**).[18-24]

Section 2. Composite Resins and Ceramics According to the Restorative Technique

There are numerous treatment modalities allowing the placement of esthetic adhesive restorations in posterior teeth (**Table 2**): The direct technique, meaning that all restorative steps are accomplished intraorally, during a single appointment; the semi-direct technique also requires a single appointment but differs from the direct one by a number of extraoral steps. The semi-direct restoration is finally luted, as is the case with the indirect technique, which implies at the very least, two appointments and the collaboration of a dental laboratory. Only direct and semi-direct restorations are made entirely chairside.

Composite semi-direct restorations can be fabricated intraorally after cavity insulation, or extraorally on a fast-setting model (usually silicone) made from a synthetic elastomer or alginate impression.[25] After fabricating the restoration, it is recommended to submit it to a thermic or photo-thermic process (postpolymerization) in a small furnace before cementation. The postpolymerization was supposed to improve the material's physico-chemical properties. In fact, the main benefits of this treatment are improved wear resistance and dimensional stability of the material.[26,27] Marginal adaptation and seal are potentially better as polymerization shrinkage is confined to the sole luting composite layer.[28,29] Practically, extraoral fabrication of the restoration on the model is a substantial advantage over direct and semi-direct intraoral techniques. However, supplemental procedures are required to make such extraoral restorations and these increase the time needed for fabrication as well as the related treatment fees.

Laboratory composites with improved strength and wear resistance are now commercially available and are increasing in popularity. Coupled with improvements in resin-based luting cements and dentin-bonding systems, indirect composite restorations may be considered appropriate for single-unit inlays or onlays. Laboratory made or semi-direct composites are generally preferred to porcelain restorations for inlays, due to their excellent aesthetic result and being less expensive for the patient (unless indirect pressable ceramics are used). Composite restorations also may demonstrate less abrasion to the opposing dentition than porcelain restorations.

There are several semi-direct systems that can produce a milled ceram-

Table 2

Classification and recommendations for adhesive restorative techniques in posterior teeth
Direct technique (chairside) – composite resins
Recommended for preventive as well as conservative Class I cavities and small to medium Class II restorations. Applied in 1.5-2.0 mm increments. Metal matrix preferred, as it is believed to improve polymerization by light reflection.
Semi-direct technique (chairside) – composite resins or ceramics
Recommended when direct techniques are inappropriate due to composite shrinkage (large volume) and indirect technique costs are not justified. Indicated for large Class I and II preparations involving a limited number of teeth. Thought to be best for premolars and first molars with favorable mouth access.
Intraoral composite inlays — Bulk or layered build up and light polymerization in vivo. Complete conversion accomplished via photothermic postcuring. Composite materials recommended are the same used for direct application.
CAD/CAM inlays — Currently limited to CEREC technology. Recommended for Class I and II composite and porcelain restorations of larger size in molars. Technique-sensitive relative to powdering and optical impression. Significant long-term data are available about these types of restorations.
Extraoral composite inlays/onlays — Recommended for improved esthetics and morphology of composite restorations as it allows more sophisticated layering techniques. Can be used for moderate to large-size cavity preparations with or without ideal access. A fast-setting silicone model material is required for this technique (e.g., Mach2 and Blue Mousse by Parkell).
Indirect techniques – composite resins or ceramics
Recommended for *serial* restorations when esthetics and dynamic occlusion issues are of primary concern.
Indirect composite inlays — Recommended for *serial* restorations *without* cusp coverage or with *limited cuspal coverage* leaving at least one functional cusp. Should be avoided for large areas of occlusion or stress.
Indirect ceramic inlays/onlays/overlays — Laboratory processed restorations best indicated for larger *serial* restorations that *include* cusp coverage. Most long-term data involves these types of restorations.

ic restoration: The CAD-CAM and the "pantograph" systems. The costs of CAD-CAM systems are high and the resulting restorations yield limited esthetic results when compared with other restorative techniques. The well-known CEREC system (Sirona, Charlotte, N.C.) is undoubtedly the most practical and integrated system. It represents a concrete contribution of new technologies to the dental profession and it probably reflects the future of restorative dentistry. The CELAY pantograph (Mikrona, Spreitenbach, Switzerland) is a totally computer-free system that allows the replication of an intraorally made resin inlay into a ceramic inlay. This replication consists in the milling of a ceramic block by burs and discs directed by the movement of similar form guides touching the resin inlay. The main disadvantage of the CEREC and CELAY systems is the cutting (subtractive process) of occlusal anatomy inside the ceramic or resin. This procedure generally results in a simplified morphology. An additional cosmetic firing may improve the final esthetics.

There are several types of ceramic materials used to fabricate posterior restorations in the laboratory, among others:

Traditional feldspathic porcelain is one of mostly frequently used materials to fabricate the posterior porcelain restorations. When combined with hydrofluoric acid etching and silanization, they show extremely reliable bonding to resin. Both refractory die and platinum foil techniques could be used to fabricate the restoration. Excellent esthetic, marginal fit, and function can be achieved with feldspathic porcelain restorations.

Pressed ceramic (e.g. Authentic, Microstar, Lawrenceville, Ga.; Empress, Ivoclar Vivadent, Amherst, N.Y.) offers two elaboration modalities: the reinforced pressed porcelain is used to fabricate either an entire restoration or only a core. This latter option allows esthetic improvements and characterization by additional ceramic firing. Although esthetic characterization remains limited compared to the full-thickness layering than can be applied with the refractory die technique, pressed ceramics may offer the best esthetics/economics ratio of all techniques for posterior indirect porcelain restorations.

Slip casting (In-Ceram Spinell, Vita Zahnfabrik, Bad Säckingen, Deutschland) can generate restorations with higher intrinsic strength compared to other systems. The basic method was originally marketed for full crowns and later adapted to bonded porcelain restorations with the use of spinel ($MgAl_2O_4$) instead of alumina. Due to the high crystalline content of this material, traditional hydrofluoric acid etching is not effective. Resin bonding to In-Ceram alumina, for instance, requires tribochemical silica coating or use of a special resin monomer.

Machined ceramics (e.g. Cerec InLab, Sirona; CELAY, Mikrona) even though originally designed for chairside use, have also become popular for laboratory use. Bonded porcelain restorations made from machined ceramic suffer from shade uniformity and rather simplistic anatomy, unless additional porcelain firings are carried out.

Section 3. Composite vs. Ceramics According to In Vitro and In Vivo Studies

Using simulated chewing fatigue, indirect composite and ceramic inlays seem to perform very similarly, with a slight advantage for ceramic restoration with regard to their adaptation to dentin, their marginal adaptation and their ability to stabilize the cusps.[30-32] Some of these differences might very well be become clinically insignificant with the advent of immediate dentin sealing (see Section 6). In vivo, indirect composite and ceramic inlays seem to perform very similarly on vital teeth and ceramic inlays tend to show better results for anatomic form and restoration integrity.[33] Barghi and Berry demonstrated 100 percent success with porcelain overlays at four years despite the fact that they did not use immediate dentin sealing.[34] The porcelain overlay seems to be a very promising restoration in term of mechanical resistance and stress distribution as demonstrated by Magne and Belser.[35] Cerec inlays have the best overall survival rate (89 percent at 10 years) and their annual failure rate is comparable to gold restorations.[2,36]

Considering the mean annual failure rates in posterior stress-bearing cavities, amalgam systematically exceeds adhesive restoration: 3.0 percent for amalgam restorations; 2.2 percent for direct composites; 2.9 percent for composite inlays; 1.9 percent for ceramic restorations; 1.7 percent for CAD/CAM ceramic restorations; and 1.4 percent for cast gold inlays and onlays.[2]

Interestingly, premolars systematically perform better than molars regardless of the restorative materials used.

Respect for correct indications of the different techniques (direct or luted), following established protocols, and enough time for education (learning curve) will ultimately result in excellent survival rates for esthetic adhesive restorations. From the previously mentioned studies, one also understands that the main complication with esthetic adhesive restoration is not secondary caries but fracture. Postcuring composite inlays, which has been demonstrated to improve mechanical properties in vitro and ensure the dimensional stability of inlays/onlays at the time of placement (see Section 5), does not seem to improve clinical performance. Interestingly, premolars systematically perform better than molars regardless of the restorative materials used. In small-to-medium size cavities (**Figure 2**), there is little difference in the behavior of direct vs. indirect and composite vs. porcelain restorations. There is still need to evaluate this possible difference in large restorations and cusp coverages. In the absence of additional evidence, use of porcelain should be favored in cusp coverages, overlays and all types of restorations in nonvital teeth.

Section 4. Clinical Considerations About Direct Composites

Beyond the choice of the restorative material itself, there are significant clinical considerations that will influence the performance of the restoration. Sections 4, 5, and 6 will review essential elements related to tooth preparation, restorative techniques and instrumentation, as well as practical elements for the optimal use of composite resins and ceramics.

Tooth preparation. Outline form of the preparation initially depends on the extent of the caries, demineralization of adjacent enamel, discoloration of enamel or dentin that might have a negative effect on esthetics and the geometry of the restoration to be replaced. When preparing a tooth in the perspective of an adhesive restoration, the principle of maximum tissue preservation has to be respected. This implies that certain structures such as marginal ridges, oblique ridges, and sound occlusal surfaces have to be preserved, even where enamel is not fully supported by dentin. For adhesive direct restorations, the conventional geometry of G.V. Black cavities is not optimal. Lutz et al. described the “adhesive preparation” consisting of a conservative round or ovoid proximal box and occlusal extensions, including beveling of enamel margins.[37] For metallic restoration replacement, the general cavity design is already determined and the preparation has to be completed by the beveling of enamel margins after removal of any damaged tissues. This is commonly known as a "beveled conventional preparation." Preparations for composite resins can be shallower and the occlusal outline narrower than for amalgam.[38] Etched enamel rods on a beveled margin produce a better bonding surface due to the diagonally sectioned enamel rods, which can be etched more effectively. Therefore, enamel in the proximal wall (especially slot preparations Class II cavities) should have a 45-degree bevel because prism direction is at right angles to the cavosurface.[39] Occlusal bevels are deemed unnecessary because the prism direction in the zone of the central fossa is inclined toward the fossa. By preparing the occlusal section of the cavity with parallel walls (or slight convergence), the diagonal cut across the prism's long axis thereby achieves more efficient etching. At the end of two years, no differences between beveled and nonbeveled occulsal margins could be detected in color, microleakage, caries, wear, or marginal adaptation.[40] However, smoothing of the occlusal margins by finishing with a fine diamond bur is recommended to remove possible weakened enamel and to make the margin less visible when the restoration is completed. Extensions of proximal walls are determined by the caries, existing restoration, decalcification, or discoloration in esthetic areas. The extensions are kept as minimal as possible and can be placed in contact areas.

Oscillating technology for shaping and beveling. The sole use of rotary instruments was demonstrated to be responsible for considerable iatrogenic damage to adjacent teeth. The use of safe-sided oscillating diamond tips (SonicSys, KaVo, Lake Zurich, Ill.) on an air scaler (e.g. Brasseler/NSK AS2000, Savannah, Ga., or SonicFlex 2000N, KaVo) for shaping and finishing the proximal and proximal-gingival wall can significantly reduce damage to the adjacent dentition (**Figure 3**) and soft tissues.[41-43] The air-scaler handpiece vibrates at a frequency of 6000-6500 Hz (max 3.5 bar). Five different tips with a 40 micron medium grit (SonicSys, KaVo) are used at pressure <2N.

At the end of two years, no differences between beveled and nonbeveled occulsal margins could be detected in color, microleakage, caries, wear, or marginal adaptation.

Matrix techniques. Controlling contacts and contours of direct composite restorations may prove difficult and is not dependent on the type of restorative material used (regular vs. packable). Contoured metal bands and special rings (e.g. Palodent/Bitine ring, Danville, San Ramon, Calif., or Composi-Tight, Garisson Dental Solutions, Springlake, Mich.) significantly help in obtaining adequate contact tightness (**Figure 4**).[44] When used properly, good proximal contact can be achieve consistently and predictably. In addition, the use of a metallic matrix improves polymerization by light reflection.[45]

The C-factor. The setting stress in composite resins was studied as a function of restoration shape. The shape is described by the configuration factor, C, the ratio of the restoration's bonded to unbonded (free) surfaces.[46] In the case of direct composite restorations, it was shown that in most of the clinically relevant cavity configurations (high C-factor), the shrinkage stress-relieving flow is not sufficient to preserve adhesion to dentin by dentin-bonding agents. Increased C-factor will also negatively impact the flexural strength and elastic modulus of the restorative material.[47] The above mentioned elements call for the use of techniques that might reduce C factor effects (sectioning, incremental build-up) and delay the gel point (slow-start or pulse-delay polymerization).

Layering techniques. There are many different direct filling techniques, including simple ones, like the "bulk" restoration, and more sophisticated ones, like the "three-sited light-curing technique."[48] The challenge of direct composites is that the placement technique has to compensate for the unavoidable composite polymerization shrinkage, especially for Class II and larger Class I preparations. Shrinkage stresses negatively influence the mechanical properties and marginal integrity of the restorative material.[47] To that effect, numerous procedures have been proposed: segmentation of the polymerization by multilayer techniques (horizontal, three-sited, oblique), use of condensation and polymerization tips, or placement of glass inserts to reduce the volume of the shrinking material, and more recently, the use of soft-start polymerization.[49-53] The very simple horizontal layering technique along with the use of a filled three-step etch and rinse adhesive (Optibond FL) can be recommended as it proved to be efficient in maintaining high bond strength to dentin.[54] A perfect

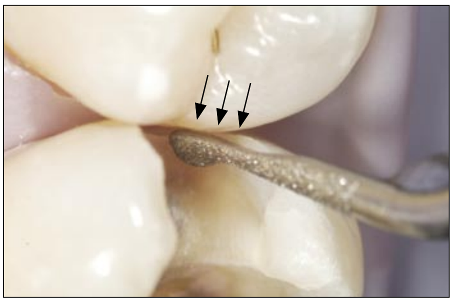


Figure 3. Oscillating hemispherical tip (No. 32, KaVo) is used to shape and finish the proximal aspect of the preparation for a direct composite. The polished nonworking side of the tip can be guided by the intact adjacent tooth surface (arrows). Along with other tip shapes, these instruments allow the perfect designing of different butt, chamfer or bevel margin finish line with no risks for iatrogenic damage to the adjacent dentition.

Figure 4. Example of sectional metal bands with separation ring (Composi-Tight Gold, Garisson Dental Solutions) to secure contact points with direct composite restorations.

gingival seal and adaptation of direct composite resin restoration cannot predictably be obtained despite the use of the aforementioned placement techniques. However, the clinical relevance of this imperfect seal is not known. It should, however, be pointed out that polymerization shrinkage can be only partially compensated, which led to the development of semi-direct and indirect techniques for larger restorations. The use of opaque and warm shades at the bottom to translucent and lighter shades at the top and the application of intensive coloring resins either on the restoration surface or preferably under the last composite layer can result in more natural appearing restorations (**Figure 5**).[55]

Section 5. Clinical Considerations Regarding Semi-Direct Techniques

Large Class I and II cavities cannot be adequately restored using a direct technique. The early development of semi-direct techniques, was justified by the necessity to reduce the contraction shrinkage and consequently to improve marginal adaptation and seal.[56,57] As with direct restorations, semi-direct techniques are mainly advocated to restore a limited number of teeth. When the teeth can adequately be accessed, large Class I and Class II cavities can be restored with either intraoral composite inlays or with CEREC (Sirona) or CELAY (Mikrona) ceramic inlays. These specific semi-direct systems require crucial intraoral steps and are therefore more suitable for bicuspids and first molars. Principles for tooth preparation of semi-direct restorations are essentially the same as those used for indirect restorations (see Section 6).

Intraoral composite inlays. The inlay is made by placing one or two composite increments inside the isolated cavity. After intraoral polymerization, the inlay can be removed provided that the cavity has been properly tapered and isolated. The inlay can be additionally subjected to a photothermic treatment (post-polymerization process). This additional procedure results in the inlay reaching the optimal resin conversion rate in a few minutes, ensuring dimensional stability and maximal hardness of the composite material. A 10-year follow-up view of an intraoral inlay is featured in **Figure 2c**. Intraoral inlays are not currently used at USC School of Dentistry for two reasons:

- MOD cavities or cavities with a complex geometry may be problematic because of the mesio-distal shrinkage component, which tends to lock the inlay into the prepared tooth.
- The application of optimized dentin bonding involves a technique called immediate dentin sealing (see Section 6), which also tends to lock the inlay into the prepared tooth because of the adhesion to the sealed dentin.

Cerec/Celay. The CAD-CAM CEREC system (Sirona) utilizes an optical impression of the preparation taken with a miniature camera, the processing of the resulting video image, and the machining of a ceramic block controlled by a computer. Besides the delicate tooth preparation powdering process (to block light reflections during optical impression), another shortcoming of the system is the difficulty to adequately position the camera over second molars and in patients with limited mouth opening. An additional criticism of this method is the simplified occlusal anatomy resulting from the cutting of very hard porcelain or glass ceramic. Nevertheless, CEREC is the only semi-direct technique that can be recommended to restore an endodontically treated tooth in the form of a porcelain overlay (complete occlusal coverage). In this case, total occlusal coverage (overlay) is recommended (see Section 6). The CELAY pantograph is based on the duplication of an intraorally made resin inlay into a ceramic inlay. This procedure also requires good operatory access to complete the original inlay. As is the case with the CEREC, this system suffers from shade uniformity and simplistic anatomy; unless an additional porcelain firing is made.

Extraoral composite inlays/onlays. The interesting feature of this approach is to extemporaneously fabricate the inlay/onlay using a hard, fast-setting silicone model. Alginate for the impression and a combination of bite

Figure 5. Proximal ridges are intact on this molar, which represents the ideal indication for direct composite restoration (a). Cavity preparation after caries removal, beveling and bonding (b). Composite was stratified using the so-called "sandwich" technique, comprising a base of dentin-like shades (c-e) that are characterized with intense stains (f) and covered with more translucent masses (g-j). Each cusp and anatomical lobe can be cured separately, which allows the elaboration of an extremely sophisticated morphology and functional masticatory surface (k).

Figure 5a.

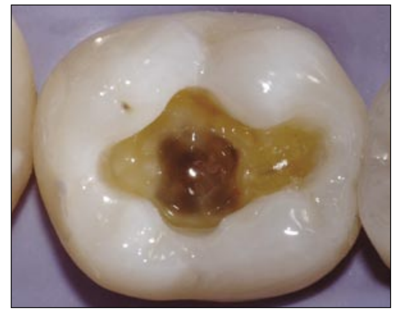


Figure 5b.

Figure 5c.

Figure 5d.

Figure 5e.

Figure 5f.

Figure 5g.

Figure 5h.

Figure 5i.

Figure 5j.

Figure 5k.


Figure 6a.


Figure 6b.


Figure 6c.

Figure 6. Large MOD cavities on teeth Nos. 30 and 31 are ideal for extraoral inlays. Using an alginate impression (a) and fast-setting silicon materials (b, Blue Mousse and Mach 2, Parkell), individual working dies (c) were obtained in six minutes.

registration material (e.g. Blu-Mousse, Parkell, Farmingdale, N.Y., and flexible hard silicone (e.g. Mach 2, Parkell) for the working model can be used (**Figure 6**, from impression to finished dies in six minutes). Unlike the intraoral technique, small undercuts in the preparation are tolerated. The inlay can always be removed from the elastic model and be seated in-mouth after the corresponding intraoral adjustments have been made. The esthetic potential and anatomy of extraoral composites is greatly improved by the possibility of performing more sophisticated layering than can be accomplished intraorally. As in the case of intraoral inlays, post-polymerization treatment is also indicated (placing the restoration into an oven at 212 degrees for a few minutes). In addition to improving restoration adaptation and seal because the main polymerization shrinkage is achieved without stress on the adhesive interface, the initial goals of semi-direct techniques were also to facilitate clinical procedures and to improve occlusal anatomy, contact points and related function. Today, these objectives have globally been achieved at the expense of a longer treatment time and higher treatment fees. However, it offers the only reasonable alternative in cases that cannot be treated by direct restorations or do not justify the use of indirect techniques. A 14-year follow-up view of an intraoral inlay is featured in **Figure 2d**.

Section 6. Clinical Considerations About Indirect Ceramics

The comparatively low elastic modulus of most composites can never fully compensate for the loss of strong proximal enamel ridges, especially in extremely large Class II restorations. In these situations, including those with cusp coverage, indirect ceramic inlays/onlays seem to be best alternative.[31,35,58,59] In the particular case of total occlusal coverage in vital teeth with a short clinical crown, ceramic indirect overlays are indicated.[34,35,58,59] Luting procedures of semi-direct and indirect bonded restorations follow the same specific steps described elsewhere including the immediate application of the dentin bonding agent (before impression taking) and use of a regular light-curing composite as the luting agent.[60,61] Dual-cure composite cements can be omitted in this approach because bonded porcelain restorations seem to offer sufficient translucency for effective light curing.[62] The rigorous application of this sequence is imperative to avoid postoperative sensitivity.

Tooth preparation. As is the case in direct restorations, outline preparation form initially depends on the extent of the caries, demineralization of adjacent enamel, discoloration of enamel or dentin that might have a negative effect on esthetics and the geometry of the restoration to be replaced. For metallic restoration replacement, the general cavity design is already determined and the preparation has to be completed by the tapering of proximal margins after removal of any damaged tissues. Dentin undercuts resulting from existing cavity design or caries removal do not need to be eliminated as these concavities will be filled by the associated application of immediate dentin sealing and composite before making the impression (see next section). To allow for the use of solely light-cured composite luting agents, cavities deeper than 4 mm at the occlusal level and 6 mm at the proximal level will require the placement of a composite base. Deep subgingival proximal margins must be elevated with a direct composite provided that rubber dam and matrix placement (tight adaptation) is possible.[63] If successful isolation and adaptation of the composite cannot be achieved, surgical exposure of the margin will be required prior to restoration. For optimal finishing and adaptation, occlusal and proximal shoulder margins are recommended. Thin isolated remaining cusps (< 2 mm at the base or when

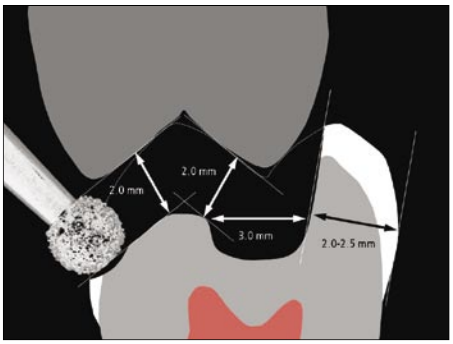


Figure 7. Recommendations for porcelain restoration dimensions. Note the “hollow chamfer” margin design that can be obtained with a round bur to ensure both an optimal marginal adaptation and a nice esthetic blending.

Figure 8. KaVo Prep Ceram (Nos. 51 and 52) tapered tip with optimal “inlay box” shape.

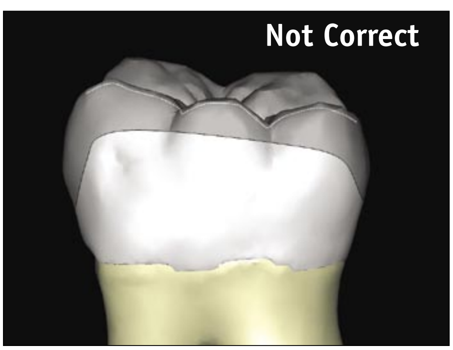


Figure 9a.

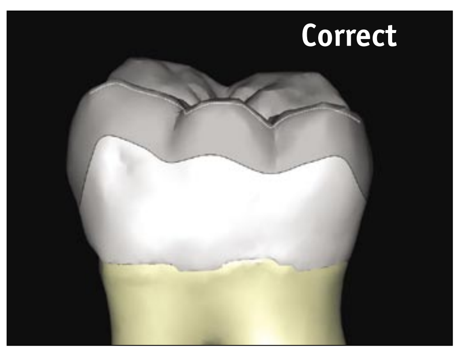


Figure 9b.

Figure 9. In case of conservative (less esthetic) type of cuspal coverage, one must be careful to follow the tooth anatomy to allow sufficient clearance not only at the cusp tip (a), but also at the level of secondary grooves (b).

the occlusal margin is located at the cusp tip) should be covered to ensure a 2 mm overlap of restorative material. In this case, a hollow chamfer will assure both an optimal marginal adaptation and a nice esthetic blending (**Figure 7**). The proximal and occlusal extensions can be kept as minimal as possible and can be placed in contact areas. As for direct composites, proximal cavity margins can be shaped and finished efficiently without risking damage to the adjacent dentition through the use of specific oscillating diamond tips. Prep Ceram tips (Nos. 51 and 52, KaVo) are specially developed for adhesive inlays and onlays with optimum taper (**Figure 8**). Their use is also recommended after immediate dentin sealing in order to clean enamel from excess adhesive resin.

In case of more conservative (less esthetic) type of cuspal coverage, one must be careful to follow the tooth anatomy to allow sufficient clearance not only at the cusp tip but also at the level of secondary grooves (**Figure 9**). Groove areas are always characterized by high stress concentrations and also need to be supported with material thickness.[35] A preliminary wax-up and corresponding silicone guides are recommended in difficult cases.

Immediate dentin sealing, base lining and dentin build up. With the development of improved adhesives and immediate dentin sealing, the use and indications for base-liners have decreased.[61] This group of materials traditionally performs many different functions, including the “partial lining” as a biologic protection for deep preparation areas, the “total lining” for the dentin insulation against chemical or thermal injuries, and the dentin replacement as a “base” prior to further restoration procedures.[58] Today, the indication for placing a liner under an adhesive restoration is mainly for pulp protection in the form of a “partial lining” using $Ca(OH)_2$ cements.[64,65] Modern adhesives are capable replacing the “total lining” function of former varnishes and cements. Base materials are mainly indicated to reduce the volume of the inlay/onlay (e.g. excessive depth) and to create an adequate preparation geometry by providing an even cavity floor and filling up internal undercuts. For that purpose, different materials can be used. Historically, when fluoride release seemed beneficial because of high risk of restoration leakage, glass ionomers were considered.[66-68] Traditional zinc phosphate cement was also applied as a base material since its biocompatibility was demonstrated by long-term clinical use and histological study.[69] Today, internal undercuts should be filled with resin-based materials (resin-based glass ionomer or composites) to avoid destructive preparations. In severe carious lesions, the selective removal of decayed tissue may create undercuts, which are not compatible with the application of an indirect restoration. To preserve and reinforce remaining sound tooth structure, the internal tapered design should be maintained by the application of bases and/or liners (**Figure 10**).[59,61,70,71] Reducing the volume of the inlay/onlay will also facilitate the light curing of the luting agent. Use

Figure 10a.

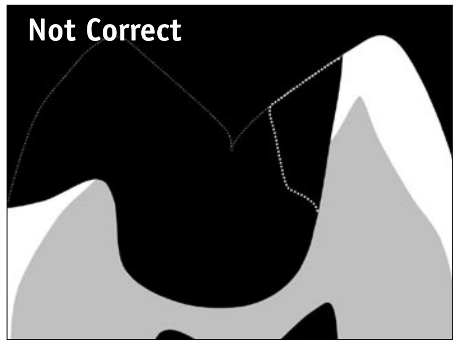


Figure 10b.

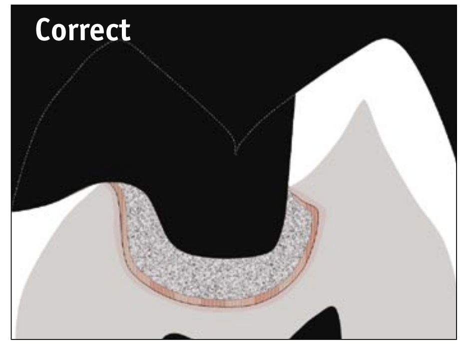


Figure 10c.

Figure 10. Large restorations, especially those that are deep in a pulpal direction, require a base build-up in order to have porcelain depth not greater than 3.0-4.0 mm. With extreme undercut walls, due to caries or prior restoration (a), instead of removing more tooth structure to get a proper path of insertion for the restoration and weakening the walls (b), use composite to fill in the undercut walls in order to preserve tooth structure (c).

Figure 11. Total occlusal coverage (overlay) is recommended on an endodontically treated tooth. A 2 mm glass ionomer (GIC) base is recommended at the pulpal floor, as it will facilitate eventual re-entry for endodontic reasons. Composite is used in conjunction with immediate dentin sealing (IDS, red interface) to reduce the volume of the inlay/onlay (e.g. excessive depth) and to create an adequate preparation geometry (by providing an even cavity floor and filling up internal undercuts).

of rubber dam is mandatory during base-lining and bonding procedures. It must be said that adequate isolation of the operating field by other means is not acceptable for posterior adhesive procedures.

Endodontically treated teeth. Endodontically treated teeth are more susceptible to fracture, not because of pulp removal per se, but due to the increased strain resulting from tooth substance loss.[72] For posterior teeth, total cuspal coverage with porcelain is recommended as it will significantly stiffen the crown and increase cusp stabilization.[35,73] As described for vital teeth, a composite resin base is indicated (**Figure 11**) to reduce the volume of the inlay/onlay and to create an adequate preparation geometry (by providing an even cavity floor and filling up internal undercuts). An additional reason for using a composite resin base in conjunction to immediate dentin sealing is the improved marginal seal and stabilizing effect of the base, reducing the risk of cusp fracture during the time between cavity preparation and the insertion of adhesive inlays.[71]

Adhesion to the existing adhesive and composite base. Immediate dentin sealing and base lining serves to protect exposed dentin between preparation and delivery of the final ceramic restoration. This procedure not only enhances bonding and protection of the pulp but prevents tooth sensitivity during the provisional phase. It has been established that a filled adhesive like Optibond FL can be efficiently reactivated by roughening with a large grained diamond or by roughening with microsandblasting.[61,74,75] This limits the final bonding procedure to enamel conditioning and application of an adhesive resin. CDA

References / 1. Magne P, Belser U, Understanding the intact tooth and the biomimetic principle. In: Magne and Belser. Bonded Porcelain Restorations in the Anterior Dentition – A Biomimetic Approach. Quintessence Publishing Co. (Chicago), 23-55, 2002.

2. Manhart J, Chen H, Hamm G, Hickel R, Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. *Operative Dent* 29:481-508, 2004.

3. Wilson NH, Curricular issues changing from amalgam to tooth-colored materials. *J Dent* 32:367-9, 2004.

4. Roeters FJ, Opdam NJ, Loomans BA, The amalgam-free dental school. *J Dent* 32:371-7, 2004.

5. Buerkle V, Kuehnisch J, et al, Restoration materials for primary molars-results from a European survey. *J Dent* 33:275-81, 2005.

6. Garcia-Godoy F, Resin-based composites and compomers in primary molars. *Dent Clin North Am* 44:541-70, 2000.

7. Garcia-Godoy F, Donly KJ, Dentin/enamel adhesives in pediatric dentistry. *Pediatr Dent* 24:462-4, 2002.

8. Osborne JW, Summitt JB, Roberts HW, The use of dental amalgam in pediatric dentistry: review of the literature. *Pediatr Dent* 24:439-47, 2002.

9. Pair RL, Udin RD, Tanbonliong T, Materials used to restore class II lesions in primary molars: a survey of California pediatric dentists. *Pediatr Dent* 26:501-17, 2004.

10. Douglas WH, Considerations for modeling. *Dent Mater* 12:203-7, 1996.

11. Morin D, DeLong R, Douglas WH, Cusp reinforcement by the acid-etch technique. *J Dent Res* 63:1075-8, 1984.

12. Morin DL, Douglas WH, et al, Biophysical stress analysis of restored teeth: experimental strain measurements. *Dent Mater* 4:41-8, 1988.

13. Morin DL, Cross M, et al, Biophysical stress analysis of restored teeth: modelling and analysis. *Dent Mater* 4:77-84, 1988.

14. Assif D, Marshak BL, Pilo R, Cuspal flexure associated with amalgam restorations. *J Prosthet Dent* 63:258-62, 1990.

15. Cameron CE, The cracked tooth syndrome. *J Am Dent Assoc* 68:405-11, 1964.

16. Cameron CE, The cracked tooth syndrome: additional findings. *J Am Dent Assoc* 93:971-5, 1976.

17. Cavel WT, Kelsey WP, Blankenau RJ, An in vivo study of cuspal fracture. *J Prosthet Dent* 53:38-42, 1985.

18. Hood JAA, Methods to improve fracture resistance of teeth. In: Vanherle G, Smith DC, eds. International Symposium on posterior composite resin restorative materials. Symposium sponsored by 3M, St. Paul, Minn., 443-50, 1985.

19. Douglas WH, Methods to improve fracture resistance of teeth. In: Vanherle G, Smith DC, eds. International Symposium on posterior composite resin restorative materials. Symposium sponsored by 3M, St. Paul, Minn. 433-41, 1985.

20. Malcolm PJ, Hood JAA, The effect of cast restorations in reducing cusp flexibility in restored teeth. *J Dent Res* 56:D207, 1971.

21. Reeh ES, Douglas WH, Messer HH, Stiffness of endodontically treated teeth related to restoration technique. *J Dent Res* 68:1540-4, 1989.

22. Linn J, Messer HH, Effect of restorative procedures on the strength of endodontically treated molars. *J Endod* 20:479-85, 1994.

23. McCullock AJ, Smith BG, In vitro studies of cusp reinforcement with adhesive restorative material. *Br Dent J* 161:450-2, 1986.

24. Macpherson LC, Smith BG, Reinforcement of weakened cusps by adhesive restorative materials: an in vitro study. *Br Dent J* 178:341-4, 1995.

25. Blankenau RJ, Kelsey WP, Cavel WT, A direct posterior restorative resin inlay technique. *Quintessence Int* 515-6, 1984.

26. De Gee AJ, Palla VP, et al, Annealing as a mechanism of increasing wear resistance of composites. D*ent Mater* 6:266-70, 1990.

27. Asmussen E, Factors affecting the quantity of remaining double bonds in restorative resin polymers. *Scand J Dent Res* 90:490-6, 1982.

28. Fülleman J, Lutz F, Direktes Kompositinlay. *Schweiz Monatsschr Zahnmed* 98:759-64, 1988.

29. Wendt SL, Leinfelder KF, The clinical evaluation of heat-treated composite resin inlay. *J Am Dent Assoc* 120:177-81, 1990.

30. Dietschi D, Moor L, Evaluation of the marginal and internal adaptation of different ceramic and composite inlay systems after an in vitro fatigue test. *J Adhes Dent* 1(1):41-56, 1999.

31. Manhart J, Schmidt M, et al, Marginal quality of tooth-colored restorations in class II cavities after artificial aging. *Oper Dent* 26(4):357-66, July-August 2001.

32. Mehl A, Kunzelmann KH, et al, Stabilization effects of CAD/CAM ceramic restorations in extended MOD cavities. *Adhes Dent* 6(3):239-45, Autumn 2004.

33. Manhart J, Chen HY, et al, Three-year clinical evaluation of composite and ceramic inlays. *Am J Dent* 14:95-9, 2001.

34. Barghi N, Berry T, Clinical evaluation of etched porcelain onlays: a four-year report. *Compend Contin Educ Dent* 23:657-70, 2002.

35. Magne P, Belser UC, Porcelain versus composite inlays/onlays: effects of mechanical loads on stress distribution, adhesion, and crown flexure. *Int J Periodontics Restorative Dent* 23:543-55, 2003.

36. Sjögren G, Molin M, Van Dijken J, A 10-year prospective evaluation of CAD/CAM-manufactured (Cerec) ceramic inlays cemented with a chemically cured or dual cured resin composite. *Int J Prosthodont* 17:241-6, 2004.

37. Lutz F, Lüscher B, et al, Die Entwicklung der perfekt adaptieren, randspaltfreien MOD-Kompositfüllung, In vitro-Befunde. *Schweiz Mschr Zahnheilk* 86:1025-41, 1976.

38. Ben-Amar A, Metzger Z, Gontar G, Cavity design for class II composite restoration. *J Prosthet Dent* 58:5-8, 1987.

39. Opdam NJ, Roeters JJ, et al, Necessity of bevels for box only class II composite restorations. *J Prosth Dent* 80:274-9, 1998.

40. Isenberg BP, Leinfelder KF, Efficacy of beveling posterior composite resin preparations. *J Esthet Dent* 2:70-3, 1990.

41. Hugo B, Stassinakis A, Preparation and restoration of small interproximal carious lesions with sonic instruments. *Pract Periodont Aesthet Dent* 10:353-9, 1998.

42. Krejci I, Dietschi D, Principles of proximal cavity preparation and finishing with ultrasonic diamond tips. *Pract Perio Aesthet Dent* 10:295-8, 1998.

43. Opdam NJ, Roeters JJ, et al, Microleakage and damage to adjacent teeth when finishing class II adhesive preparations using either a sonic device or bur. *Am J Dent* 15:317-20, 2002.

44. Peumans M, Van Meerbeek B, et al, Do condensable composites help to achieve better proximal contacts? *Dent Mat* 17:533-41, 2001.

45. Kays, BT, Sneed WD, Nuckles DB, Microhardness of class II composite resin restorations with different matrices and light positions. *J Prosthet Dent* 65:487-90, 1991.

46. Feilzer AJ, De Gee AJ, Davidson CL, Setting stress in composite resin in relation to configuration of the restoration *J Dent Res* 66:1636-9, 1987.

47. Choi KK, Ryu GJ, et al, Effects of cavity configuration on composite restoration. *Oper Dent* 29:462-9, 2004.

48. Lutz F, Krejci I, Oldenburg TR, Elimination of polymerization stresses at the margin of posterior composite resin restorations: a new restorative technique. *Quintessence Int* 17:777-84, 1986.

49. Lutz F, Kull M, The development of a posterior tooth composite system, in vitro investigation. Schweiz Mschr Zahnheilk 90:455-83, 1980.

50. Tjan AHL, Bergh BH, Lidner C, Effect of various incremental techniques on the marginal adaptation of class II composite resin restorations. *J Prosthet Dent* 67:62-6, 1992.

51. Ericson D, Dérand T, Reduction of cervical gaps in class II composite resin restorations. *J Prosthet* Dent 65:33-7, 1991.

52. Jørgensen K, Hisamitsu H, Class 2 composite restorations: prevention in vitro of contraction gaps. *J Dent Res* 63:141-5, 1984.

53. Donly KJ, Wild TW, et al, An in vitro investigation of the effects of glass inserts on the effective composite resin polymerization shrinkage. *J Dent Res* 68:1234-7, 1989.

54. Nikolaenko SA, Lohbauer U, et al, Influence of c-factor and layering technique on microtensile bond strength to dentin. *Dent Mater* 20:579-85, 2004.

55. Magne P, Holz J, Stratification of composite restorations: systematic and durable replication of natural aesthetics. *Pract Periodont Aesthet Dent* 8:61-8, 1996.

56. Mörmann WH, Brandestini M, et al, Chairside computer-aided direct ceramic inlays. *Quintessence Int* 20:329-39, 1989.

57. Blankenau RJ, Kelsey WP, Cavel WT, A direct posterior restorative resin inlay technique. *Quintessence Int* 515-6, 1984.

58. Magne P, Dietschi D, Holz J, Esthetic restorations for posterior teeth: practical and clinical considerations. *Int J Periodontics Restorative Dent* 16:104-19, 1996.

59. Dietschi D, Spreafico R, Adhesive metal-free restorations. Berlin: *Quintessence* 60-77, 1997.

60. Magne P, Belser U, Immediate dentin bonding. In: Magne and Belser. Bonded Porcelain Restorations in the Anterior Dentition – A Biomimetic Approach. Chicago: Quintessence Publishing Co., pages 270-73, 358-63, 2002.

61. Magne P, Immediate dentin sealing: a fundamental procedure for indirect bonded restoration. *J Esthet Restor Dent* 17:144-55, 2005.

62. Besek M, Mormann WH, et al, The curing of composites under Cerec inlays. *Schweiz Monatsschr Zahnmed* 105:1123-8, 1995.

63. Dietschi D, Olsburgh S, et al, In vitro evaluation of marginal and internal adaptation after occlusal stressing of indirect class II composite restorations with different resinous bases. *Eur J Oral Sci* 111:73-80, 2003.

64. Virgillito A, Holz J, Produits adhesifs dentinaires et de scellement soumis au contrôle biologique in vivo. *J Biol Buccale* 17:209-24, 1989.

65. Elbaum R, Remusat M, Brouillet JL, Biocompatibility of an enamel-dentin adhesive. *Quintessence Int* 23:773-82, 1992.

66. Schwarz ML, Philips RW, Long-term F release from glass ionomer cement. *J Dent Res* 63:158-60, 1984.

67. 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.

68. Tam LE, McComb D, et al, Physical properties of proprietary light-cured lining materials. *Oper Dent* 16:210-7, 1991.

69. Brännström M, Nyborg H, Pulpal reaction to polycarboxylate and zinc phosphate cements used with inlays in deep cavity preparations. *J Am Dent Assoc* 94:308-10, 1976.

70. Moscovich H, Roeters FJ, et al, Effect of composite basing on the resistance to bulk fracture of industrial porcelain inlays. *J Dent* 26:183-9, 1998.

71. Hofmann N, Just N, et al, The effect of glass ionomer cement or composite resin bases on restoration of cuspal stiffness of endodontically treated premolars in vitro. *Clin Oral Investig* 2:77-83, 1998.

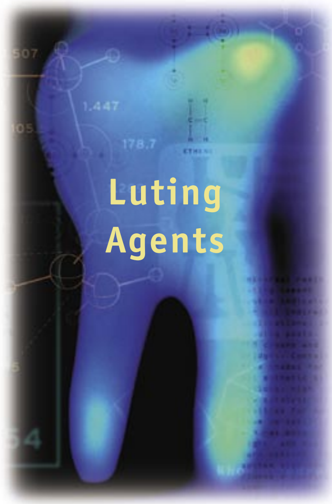
72. Panitvisai P, Messer HH, Cuspal deflection in molars in relation to endodontic and restorative procedures. *J Endod* 21:57-61, 1995.

73. Fennis WM, Kuijs RH, et al, Fatigue resistance of teeth restored with cuspal-coverage composite restorations. *Int J Prosthodont* 17:313-7, 2004.

74. Magne P, Belser U, Try-in and adhesive luting procedures. In: Magne and Belser. Bonded Porcelain Restorations in the Anterior Dentition – A Biomimetic Approach. Quintessence Publishing Co., Chicago, pages 335-69, 2002.

75. Magne P, Kim TH, et al, Immediate dentin sealing improves bond strength of indirect restorations. *J Prosthet Dent* 94:511-9, 2005.

For a printed copy of this article, please contact/ Pascal Magne, DMD, PhD, University of Southern California School of Dentistry, Division of Primary Oral Health Care, 925 W. 34th St., DEN 4366, Los Angeles, Calif., 90089-0641.



Selection of Luting Agents, Part 1

Sajid A. Jivraj, DDS, MSEd; Tae Hyung Kim, DDS; and Terry E. Donovan, DDS

Abstract

The clinical success of indirect restorations is dependent on multiple factors that include preparation design, mechanical forces, restorative material selection, oral hygiene, and selection of a proper luting agent. The selection of the luting agent is dependent on the specific clinical situation, the type of restoration utilized and the physical, biologic, and handling properties of the luting agent.

Although it is important to choose the best luting agent for each clinical situation, far greater variations in physical properties result from improper manipulation of a given luting agent than exist between different types of cements.[1] One study listed loss of retention as the third-leading cause of prosthetic replacement, with failure occurring after only 5.8 years in service.[2]

The primary purpose of the luting procedure is to achieve a durable bond and to have good marginal adaptation of the luting material to the restoration and tooth. Conventional cements have always relied upon retention and resistance forms in tooth preparations; Adhesive-type luting agents offer the clinician an added advantage by bonding to the tooth structure.[2]

Three main types of conventional "cements" are commonly used, zinc phosphate and the polyelectrolyte cements polycarboxylate, and glass ionomer cements. Because of its long history of successful clinical use, zinc phosphate is considered the gold standard against which all other luting agents are compared because of its long clinical history of successful use.

Currently, two additional types of luting agents have gained considerable popularity. These include the resin-modified glass ionomer cements and resin cements.[1] The resin cement category includes light-cured, dual-cured and chemically cured agents.

The purpose of this article is to discuss the ideal attributes of a luting agent and make clinical recommendations for their use.

The practicing clinician has many choices with regard to luting agents. No currently available luting agent is ideal for all situations and a careful choice needs to be made based on scientific rationale.

Ideal attributes of a luting agent are noted in (**Table 1**). These will be discussed in reference to currently available luting agents.

Adhesion to Tooth Structure

The primary function of a dental cement is to seal the restoration to the tooth. This would occur if the cement would biomechanically or biochemically adhere to the prepared tooth. Zinc phosphate, which has been the most popular luting agent for the past 100 years, does not chemically bond either


Guest editors / Sajid A. Jivraj, DDS, MSEd, is chairman of the Section of Fixed Prosthodontics and Operative Dentistry, University of Southern California School of Dentistry. He also maintains a private practice limited to prosthodontics in Sherman Oaks and Torrance, Calif. Terry E. Donovan, DDS, is professor and division chair, Primary Oral Health care, University of Southern California School of Dentistry.

Author / Tae Hyung Kim, DDS, is chairman of the Section of Removable Prosthodontics, University of Southern California School of Dentistry.

Acknowledgments / The patient treatment (Figures 6-10) was completed by student Ilya Mironov; Sajid A. Jivraj, DDS, MSEd, faculty supervisor. The patient treatment (Figures 13-18) was completed by student Arpita Sharma; Sajid A. Jivraj, DDS, MSEd, faculty supervisor.

to the tooth structure or the restorative material. However, when freshly mixed, zinc phosphate has a very low pH. This acidity allows for excellent wetting of the tooth and for micromechanical attachment to the prepared dentine. Retention depends on careful design of the tooth preparation and the quality of fit of the restoration. Several microleakage studies have demonstrated significant linear penetration of silver nitrate from the external margin along the restoration/tooth interface after crown cementation with zinc phosphate cement. The significance of this microleakage will be discussed later in the article (**Figure 1**).[4,5]

Table 1

Desirable properties of a luting agent

1. Adhesion to restorative material
2. Adequate strength to resist functional forces
3. Lack of solubility in oral fluids
4. Ability to achieve a low-film thickness under cementation conditions
5. Biocompatibility with oral tissues
6. Possession of anticariogenic properties
7. Radio-opaque
8. Relative ease of manipulation
9. Esthetic/color stability

The polyacrylic-based cements bond to both enamel and dentine and are also claimed to have some affinity for metal and ceramic surfaces. This category of tooth adhesive cements includes polycarboxylate and the glass ionomer, and resin-modified glass ionomer cements. Although they have some ability to bond to metals, they do not provide adequate bond strengths to metal or ceramic in some of the more demanding situations encountered.[6,7]

Polycarboxylate cements exhibit chemical adhesion to the tooth through interaction of free carboxylic acid groups with calcium. It is reasonable to assume that because of this adhesion, polycarboxylate cements would exhibit less microleakage. However, microleakage studies demonstrate they leak just as much as zinc phosphate. The glass ionomer cements form an ionic bond to the tooth as a result of chelation of the carboxyl groups in the acid with the calcium and phosphate ions in the apatite of dentine and enamel.[7]

The resin-modified glass ionomer cements also form much stronger bonds to dentine than does zinc phosphate cement. There is sufficient data to warrant their use as an alternative to zinc phosphate in luting full-coverage restorations.[8,9] Their adhesion to enamel and dentin is similar to glass ionomer cement. An added advantage is that these cements are able to bond to composite resin.

With the advent of predictable dentin bonding, the resin cements can bond to both tooth structure and restorative material. Adhesion to enamel occurs through micromechanical interlocking of the resin to the hydroxyapatite crystals and the rods of etched enamel.

Resin to dentin adhesion is obtained by infiltration of resin into etched dentin producing a micromechanical interlock with partially demineralized dentine, which underlies the hybrid layer. Adhesion to dentine requires multiple steps beginning with the application of an acid conditioner to remove the smear layer, open and widen tubules and demineralize the top 2-5 microns of dentine. The acid dissolves and extracts the apatite material and opens channels around the collagen fibers. These channels provide an opportunity for micromechanical retention. An optimal 2-5 micron zone of demineralization has been described with a 15-second application for conditioner. Prolonged application results in a deeper demineralization zone which resists resin infiltration. If complete infiltration of the collagen by the primer does not occur, the collagen within the deeper demineralized layer will be left unprotected and subject to future proteolysis and breakdown. After demineralization, a wetting agent, such as HEMA (hydroxyethyl methacrylate), is applied. HEMA is bifunctional and hydrophilic, which allows it to bond to the dentine, and it is also hydrophobic which allows it to bond to the adhesive.[10,11]

It is reasonable to assume that luting agents that present stronger bonds to tooth structure will also demonstrate less microleakage. This has been verified by both in vitro and in vivo studies.[4,5] Restorations cemented with resin and resin-modified GIC exhibit reduced microleakage when compared to zinc phosphate cement. Conventional glass ionomers also demonstrate significantly less microleakage than zinc phosphate cements. What is the clinical significance of reduced microleakage? A recent in vivo

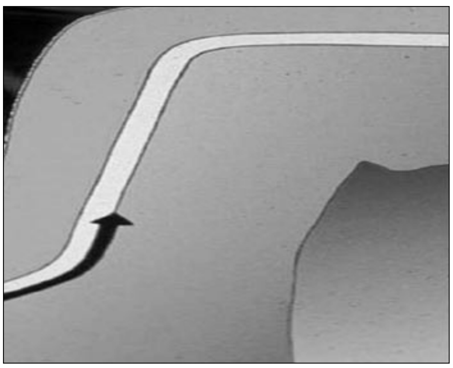


Figure 1. Leakage pathway of cast crown.

study evaluated microleakage with cast gold crowns cemented with zinc phosphate. The study evaluated eight restorations that had provided a mean service of 22 years. The teeth required extraction for periodontal reasons. When conventional tests were done on these teeth, the typical microleakage associated with zinc phosphate was demonstrated. However, there was no evidence of recurrent caries, sensitivity, or pulpal degeneration. This data calls into question the clinical significance of microleakage studies.[12] There is no evidence that improved adhesion to tooth structure improves the clinical performance of dental cements for cast restorations. However, one must be careful not to extrapolate this to the bonded restoration where adequate seal may play a major role in the survival of the restoration.

Adhesion to Restorative Material

It is also thought that a strong bond to the restoration is desirable. With conventional cements this would not be an advantage because when the crown loses retention, it is normally seen that the cement is retained within the crown. With regard to ceramic restorations luted with resin-based cements, there is controversy whether one should achieve a stronger bond to the restorative substrate by silanating the ceramic or not.

The research on silanization reports higher bond strengths to the ceramic.[13] It reports chemical bonding between the ceramic and the resin composite. Use of silane improves the wettability and contributes to the covalent bond formation between porcelain and resin composite. It also theoretically supports reinforcement of the ceramic through chemical bonding, theoretically decreasing the likelihood of fracture.

Those against silanization argue that a greater bond strength to the ceramic is not required, the micromechanical bond to the etched ceramic is adequate. Increasing the bond to the restorative substrate results in uniaxial shrinkage of the cement toward the restoration and significant contraction gaps develop at the tooth cement interface. These gaps are thought to result in microleakage and continue to be a source of sensitivity.[14]

If the practitioner decides to silanate, a number of variables need to be considered. When using silane, one mix and two mix silanes are available. The silane coupling agents contain a high volume of various solvents. Improperly sealed or open containers will allow evaporation of the solvents and increase the concentration of the coupling agent. If this occurs, the silane may act as a separating medium reducing the bond strength between the ceramic and the composite.

Various authors have also evaluated the effect of silanization of porcelain on the bond strength to composite. The general trend observed was that application of a silane coupling agent resulted in improved bond strength. The heat treatment showed increased bond strength, and it was demonstrated that delaying the time between silanization and bonding resulted in increased bond strength.[15] From a practical perspective, delaying the bonding time is not feasible.

Other studies have also investigated the effect of the post-silanization drying time with a stream of warm air to determine if this could increase the tensile bond strength of composite to ceramic over that produced by room temperature drying.[16] Higher bond strengths were achieved with warm air and the failure mode was cohesive within the composite. The results of the study concluded that use of a miniature blow dryer is effective in enhancing bond strength of ceramic to composite than drying at room temperature.

Silane must be used appropriately. Imperative procedures include properly sealed containers to prevent evaporation of solvent, heat drying following applications, and a delay in bonding time. Those who do not use silane must exercise proper care in etching the ceramic with hydrofluoric acid after clinical try-in and remove ceramic precipitates that form on the internal surface of the restoration.[17] These residues have a potential to reduce the bond strength of the ceramic to the composite (**Tables 2**, **3**).[18]

Indirect composites were introduced as an inlay/onlay material in an attempt to improve the mechanical properties over direct restorative materials. However, there is no clinical evidence to show that an improvement in physical properties translates to an improvement in long-term clinical success. A number of studies have evaluated adhesion between the resin cement and the inlay/onlay material. Anecdotally, many clinicians have observed debond-

Table 2

Reasons in favor of using silane

Advantages
1. Higher bond strengths to ceramic
2. Provides chemical bonding
3. Reinforcing the ceramic decreasing propensity of fracture

Table 3

Reasons against using silane

Disadvantages
1. Don't need a higher bond strength to ceramic
2. Potential for postoperative sensitivity
3. Silane improperly used can act as a separating medium.

ing between the luting resin and composite inlay.

Microsandblasting of the composite surface is a prerequisite for optimal bonding.[19] Indirect composites are also secondarily cured and studies have shown that this curing causes a significant reduction in availability of the bonds and a consequent reduction in bond strength to composite.[20] One author evaluated the adhesive bond strength of resin cements to resin composites with and without secondary curing and with and without microsandblasting.[18] The results of the study showed that secondary curing only without sandblasting resulted in a decreased bond strength to the resin cement. Sandblasting improved the bond strength. The greatest bond strengths were achieved without secondary cure and with sandblasting.[21] When using these types of restorations, microsandblasting of the fit surface should always be performed prior to bonding.

The authors have also evaluated various surface treatments of indirect resin composites prior to luting (microfilled and hybrids).[18] The effect of hydrofluoric acid, phosphoric acid, microsandblasting, and combinations were investigated. The results of the studies showed that phosphoric acid and hydrofluoric acid alone did not produce sufficient roughness to create mechanical retention. In fact, the use of the hydrofluoric acid degraded the surface of the composite. With microfilled composites, the glass particles were embedded in the resin and were unavailable for etching. Hybrids had higher bond strengths with etching than did microfills. The highest bond strengths were achieved when microsandblasting followed by etching with phosphoric acid. The microsandblasting roughens the surface and the phosphoric acid cleans any debris (**Table 4**, **Figures 2-6**).

Resin-bonded fixed partial dentures have an undeserved poor reputation in the minds of many practitioners who believe that such prostheses have a relatively short life span. This reputation has resulted from improper teaching and execution of this restorative service.[1] It has been shown that with proper resistance and retention form that long-term clinical service of resin-bonded fixed partial dentures is at least equal to conventional cemented prostheses.[22]

Various methods to develop adhesion between a prosthesis and a tooth have been developed. Initially the approach was macroretentive but gradually adhesive procedures involving micromechanical and chemical bonding became available.[23,24]

Another approach is the use of adhesion promoters such as silica coating, tin plating, tribochemical coatings, and metal primers, which have been developed to improve the bond between metal and the more conventional Bis GMA or urethane dimethacrylate resins. An important consideration in adhesion is whether one is seeking to bond a base metal alloy or a precious metal alloy.

For the resin-bonded fixed partial dentures, the metal is etched, which removes one of the phases and provide micromechanical retention. This provides a surface onto which composite resin can adhere. The composite luting resins are very similar to composite resin restorative materials in that they consist of Bis GMA, or urethane dimethacrylate resins, and a glass filler. Where these resins are different is that they are a two-paste system, which are either chemically or dual-cured. The filler particle size is less and the filler loading tends to be slightly less in order to ensure a lower film thickness.

One of the drawbacks of the technique is the reluctance of clinicians and laboratory technicians to use to beryllium containing Ni-Cr alloys. Nonberyllium containing Ni-Cr alloys do not etch as well.

Table 4

Pretreatment of indirect composite prior to bonding

- Secondary curing causes reduction in availability of bonds.
- Microsandblasting improved the bond strengths.
- Highest bond strengths are achieved with microsandblasting followed by cleaning with phosphoric acid.

Figure 2. Recurrent caries beneath amalgam restoration patient requested esthetic alternative.

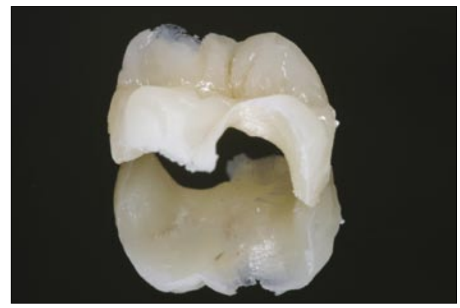


Figure 3. Indirect composite restoration.

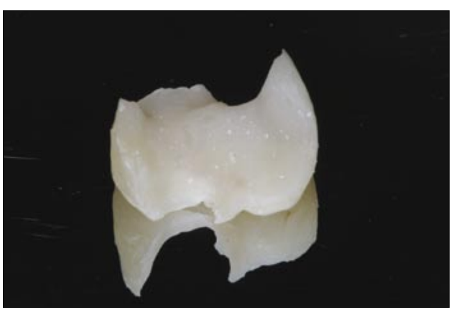


Figure 4. Fitting surface of indirect composite microsandblasted to improve bond strength.

Figure 5. Thirty-seven percent phosphoric acid used to clean debris on fit surface.

Figure 6. Indirect composite on No. 2.

Precious metal alloys also cannot be etched since they have a relatively homogenous microstructure, hence it is not possible to use the etching technique for resin bonding with these alloys.

Because of the trend to move away from beryllium-containing alloys, laboratories had to find some other means of bonding to the alloy. The problem is Bis GMA and UDME resins do not bond well to etched metal surfaces and rely primarily on micromechanical and physical adhesion. In order to improve the adhesive bond to metal, a variety of composite resins have been developed in which the resin component has been modified to be able to bond chemically to the metal surface, these luting agents are referred to as chemically adhesive luting resins to differentiate them from the Bis GMA resins C&B superbond is one example (based on carboxylic monomer 4 META).

Another luting agent which has been modified to contain a phosphate monomer is Panavia 21 from Kuraray (MDP methacryloxyethylphenyl phosphate). Resin bonding is facilitated by the high affinity of the carboxylic acid or phosphoric acid derivative containing resins for the metal oxide on the base metal alloy, they can provide a durable bond to nickel chromium alloys. They have low affinity for precious metal alloys, such as gold and palladium, due to lack of surface oxide coating.

Adequate Strength to Resist Functional Forces

Many clinicians believe that increased strength of the luting agent will increase the retention of the castings on the teeth. Scientific evidence for this belief is lacking and it is becoming increasingly clear that crown retention is a function of resistance and retention form coupled with accuracy of fit of the casting. Clinical experience with provisional luting agents and resin-bonded fixed partial dentures support this belief.[1]

There are substantial differences in strength between the different groups of luting agents. The question always arises, if it is stronger, does it mean it is better?

Figure 7. Short clinical crowns, which would lack resistance and retention form if prepared for full-coverage restorations.

Figure 8. Preparations must provide adequate resistance and retention form.

Cement strengths are generally compared using the parameters of compressive strength and diametral tensile strength, with the latter being considered more important to clinical performance. Compressive strength tests are done with cylindrical samples and diametral tensile tests are done using disc-like samples. Neither of these tests evaluates the cement in the mode, in which it is used, which is a thin film of 25 microns. Testing will reveal that zinc phosphate has the lowest compressive and diametral tensile strength while resin cements have values which are much higher. The clinical significance of these values can be questioned. If the clinician is confronted by preparations with a short wall height, can the strength of resin cements be used to provide long-term retention for restorations?

Increased strength of cements will not increase retention of castings cemented on prepared teeth (**Figures 7, 8**). It may provide retention for the prostheses in the short term but eventually the cement will undergo fatigue failure and the prosthesis will decement. Increasing the strength of the cement will not compensate for lack of retention and resistance form.[1]

Many clinicians have experienced delivering a definitive restoration with a provisional cement only to find that the restoration is very difficult to remove. These provisional cements have much inferior physical properties than the permanent cements, yet still retain the casting in place over the long term. This calls into question the value of increased strength.

Lack of Solubility in Oral Fluids

Significant differences in solubility exist between the different luting agents. The literature on solubility demonstrates the necessity of relying too heavily on in vitro data to predict clinical performance. Tests are done in which the cement sample is immersed in a solute for 24 hours and the weight loss of the sample is recorded or an increase of the cement component in the solute is measured. Under these conditions, zinc phosphate appears to be the least soluble and glass ionomer the most soluble. However clinical studies show the opposite to be true.[24-26] The difference between in vitro and vivo studies can be explained by patient variability and timing of the test. Tremendous variability can exist between patients in terms of their potential to dissolve cement with some dissolving much cement and others dissolve none. The timing of the test is also critical. Glass ionomer cement is quite soluble within the first 24 hours and perform poorly in a 24-hour test. However after the initial 24 hours, glass ionomers are quite resistant to dissolution and hence perform very well in a long-term clinical test. The latter is more clinically significant.[1]

The issue should not be the solubility of the cement but rather the fit of the restoration. With excellent fitting restorations solubility is secondary.

Ability to Achieve a Low-Film Thickness Under Cementation Conditions

Film thickness is influenced by a number of factors including particle size of the powder, cementation force and technique, viscosity and the use of specific techniques such as diespacing, venting, or placement of escape channels.

ADA stipulations state that luting agents must achieve a film thickness of no more than 25 microns under the conditions of the specification test. With this test, a mix of cement is compressed between two glass slabs with a specified amount of force, and then the increase in thickness of the two slabs is measured. This increase in thickness is designated film thickness. Most luting agents can achieve the required film thickness under the specifications of the test but the same luting agent may produce excessive casting elevations when the restorations are luted in place.[27,28] What the clinician must understand is that values reported in trade journals may not be representative and film thickness is more than just a material property. Ultimately, it's how the practitioner manipulates the luting agent rather than the physical property of the luting agent itself.

Biocompatibility With Oral Tissues

When luting agents are used they will invariably contact a large area of dentin, hence the susceptibility to producing postoperative sensitivity or pulpal inflammation is a very important consideration.

An ideal luting agent would not be harmful to the dental tissues. It was long thought that cements containing phosphoric acid cause pulpal inflammation as a result of their low pH. For many years clinicians applied copal varnish over the prepared tooth to protect the pulp from the acidity of zinc phosphate cement. Research has challenged this long-held belief and it is likely that all commonly used dental cements elicit no long-term pulpal response and hence meet the criteria for biocompatibility.[29]

Postoperative sensitivity has also been rightly or wrongly attributed to the luting agent used. Clinical symptoms such as sensitivity after crown cementation are more likely because of microleakage than pulpal inflammation resulting from damage caused by the luting agent. Well-controlled clinical trials using a strict protocol for cementation have demonstrated that the sensitivity is clearly operator-related and can essentially be prevented with proper technique.[30,31]

A concept which has been introduced during the last few years is the idea of "immediate dentin sealing." This has been primarily advocated for adhesive-type restorations. It has been demonstrated that effective adhesion can be achieved by immediately applying the adhesive following tooth preparation.[32] Following application of the adhesive and curing, an impression is made. It appears that immediate dentine bonding has several advantages by sealing the dentinal tubules prior to impression-making:

- No contamination of the dental tissues by impression material or cement,
- Stabilization of the adhesive layer prior to subjecting the adhesive interface to stresses, and
- Reduction of postoperative sensitivity.

It is likely that all commonly used dental cements elicit no long-term pulpal response and hence meet the criteria for biocompatibility.

It appears to be a perfectly rational way to seal and protect the dentino-pulp complex, prevent sensitivity, and bacterial leakage during the provisional phase.

Possession of Anticariogenic Properties

Many luting agents have been described as having anticariogenic properties. A number of these have been marketed on this premise. Many manufacturers claim that their specific brand of cement releases fluoride, but the clinical efficacy of such claims has not been investigated.

The fact that a material contains fluoride does not necessarily endow it with anticariogenic properties. Sufficient concentrations of fluoride must be released over a period of time, and the material itself should not suffer from any significant degradation. Of the conventional cements, the glass ionomers have been reported to have long-term fluoride release and cariostatic activity of these cements has been proposed.[33] However, even if fluoride is released, one must question just how much fluoride is released from the margins of a well-fitting restoration, and whether this amount of fluoride has any significant impact. Scientific studies have been inconclusive in showing that the thin film of cement at the margin of a restoration has any significant clinical therapeutic value as a cariostatic agent.

Radio-opacity

An ideal luting agent should be radio-opaque to enable the practitioner to distinguish between the cement, the tooth, and the restoration. Combinations of composite luting cements/and or glass ionomers may show gap-like features because of difference in radio-opacity. It is important that dental cements have greater opacity than dentine.

It is impossible radiographically to detect excess luting agent if the material is radiolucent. In practice, luting agents come in a wide range of radio-opacities.

One study showed zinc phosphate to be the most radio-opaque. The dual polymerized and conventional glass ionomer showed the same as human enamel. The RMGI are intermediate between enamel and dentine. The autopolymerizing luting agents had similar radio-opacity to dentine and were the lowest.[34]

Relative Ease of Manipulation

One of the most important attributes of any dental material is that it be user friendly and relatively easy to manipulate.

It is important that cements be mixed according to manufacturer's recommendations and with meticulous attention to detail, far greater variations occur from improper mixing rather than selection of type of cement. Cements may be handmixed or come in pre-dosed capsules or syringes. The auto-mix cartridges are an advantage because they allow a consistency of mix, convenience, and less clean up is required. Disadvantages include greater expense and the inability to vary the viscosity.

Amongst the conventional luting agents, zinc phosphate appears to be the least technique-sensitive. A specific protocol is required with the use of zinc phosphate, and as long as these recommendations are followed long-term success will be achieved.[1]

Polycarboxylate cements are also more technique-sensitive. They exhibit a thixotropic behavior where an apparently viscous mix flows readily under pressure. However, they exhibit a rapid increase in film thickness that may impede proper seating of a casting. During setting, polycarboxylate cements go through a rubbery stage, and at this time should remain undisturbed during setting to prevent it from being pulled away from under the margins.

One disadvantage of polycarboxylate cements is they exhibit plastic deformation and thus the cement is not suited for use in areas of high masticatory stresses or in cementation of long-span prostheses.[35] Their use is confined to single units in low stress areas. These cements may also be used to secure long-term provisional restorations.

Resin cements are extremely technique-sensitive because of their inherent polymerization shrinkage and their sensitivity to moisture. Using resin cements with restorations that have subgingival margins is problematic. Removal of the excess becomes difficult because of the hardness of the cement and its adhesion to the tooth.

Resin-modified glass ionomer cements are less technique-sensitive than the resin cements and in auto-mix cartridges, can prove to be an extremely efficient way of delivering cast restorations. One of the disadvantage of RMGIC is the hydrophillic nature of the polyhema, which results in increased water sorption and subsequent plasticity and hygroscopic expansion. The continual water resorption does have deleterious effects. Potential for substantial dimensional change contraindicates their use with all-ceramic type restorations.

The working time and setting time are considerations in the choice of luting agent, the longer working time being needed for long-span prostheses vs. single-unit restorations.

The working time and setting time are considerations in the choice of luting agent, the longer working time being needed for long-span prostheses vs. single-unit restorations. With conventional luting agents, the working time can be varied by utilizing techniques such as slaking, incremental mixing, use of a chilled slab, and mixing over a wide area to dissipate the heat of the exothermic reaction.

With resin cements there is a choice between dual-cured and light-cured resins.

The light-cured resins have some purported advantages in that working time is increased, the ability to remove excess, and reduced finishing time. Dual-cured cements have traditionally been used when ceramic thickness did not allow light penetration for maximal conversion of the luting cement. Disadvantages of dual-cured cements include porosity from mixing, reduced working time, degree of conversion, and color instability due to amine degradation. One author investigated both dual- and light-cured cements in regard to conversion rate under cerec inlays.[36]

The following parameters were evaluated: the effect of ceramic thickness, use of a light reflecting wedge, and varied the time of curing. Following curing, Vickers hardness at the pulpo-axial wall was measured. It was concluded that dual-cured cements offered no advantages over the light-cured cements, provided an extended curing mode 120 seconds was used. One question which often arises is curing of the luting agent beneath excessive thicknesses of ceramic. An alternative approach to avoid excessive thicknesses of ceramic is to build the tooth up in composite material.

The Young's modulus of composite is more like dentin as opposed to ceramic, which is a more enamel-like material. The core of the tooth may be built up to minimize thickness of ceramic in the definitive restorations. Traditionally, clinicians removed tooth structure to eliminate undercuts so that the preparation would allow a single path of insertion. Today, clinicians are able to block out undercuts with composite and avoid the unnecessary destruction of tooth tissue so that a single path of insertion may still be realized. In this manner, the thickness of ceramic can be optimal for use of light-cured resins.[37]

Another category of luting agents that has recently been introduced is the auto-adhesive group. It is not the purpose of this article to describe the different mechanisms of adhesion of resin cements but briefly just to describe the three categories.

Etch and rinse, self-etch adhesive along with a low-viscosity resin composite, and the self-etch, which also includes the self-adhesive resin. This third category of resin cement is becoming very popular with practitioners because of the reduced chairtime and a simpler application protocol. It combines the adhesive and resin in one product eliminating the need for pretreatment of both tooth and restorative material prior to cementation.

The adhesive properties are based on acidic monomers that demineralize and infiltrate the tooth substrate resulting in micromechanical retention. A secondary reaction of this cement is to provide chemical adhesion to hydroxyapatite.

Several other purported advantages from manufacturers include:

■ It is dual-cured and achieves a bond to tooth structure similar to that achieved by multistep adhesives,

■ Mechanical properties are supposedly superior to zinc phosphate and glass ionomer cements,

■ It has excellent moisture tolerance and manufacturers state that a rubber dam need not be used, and

■ Little risk of postop sensitivity because the dentin is not etched, the smear layer is not removed, and the dentinal tubules remain closed. The multistep of etching, priming, and bonding are not required so there is little risk of overdrying, overly moist dentin and generation of nanoleakage by inadequate preparation of the primer and bonding system.

One group of authors evaluated the microtensile tensile bond strength of RelyX Unicem(3M Espe) to enamel and dentin.[38] The experimental protocol also evaluated the interaction of this material with dentin by means of high resolution electron microscopy. The authors compared the microtensile bond strength to enamel and dentine with and without etching after 24-hour water storage compared to the bonding effectiveness of the control cement Panavia F (Kuraray). The interface between the dentine and the luting agent was also examined with a scanning electron microscope.

There is no ideal luting agent for all procedures; and choice is dependent on physical properties, technique sensitivity and evidence base.

The results showed that microtensile bond strength was significantly lower than that of the control cement to etched enamel, while there was no significant difference to dentin. Acid etching raised the microtensile bond strength to that of the control cement but was detrimental to the dentine bonding effectiveness. This was due to inadequate infiltration of the collagen mesh.

SEM evaluation showed that Rely X cement interacted only superficially with enamel and dentine, and application, using some pressure, is required for close adaptation of the cement to the cavity wall. There was negligible chemical bonding.

Esthetics and Color Stability

Esthetics, although not a major consideration with metal and metal ceramic restorations does become an issue with translucent porcelain restorations. Light transmission and color stability of the luting agent are important in this regard. Expanded kits of resin cements with tints, opaques, and multiple shades are tailored to anterior ceramic restorations and supposedly allow subtle shade corrections to be made. Caution should be exercised in this approach. In practice, the color of a try-in paste may differ significantly from the luting agent. Of three shades of three bands tested by one author, all but two had easily detectable color differences.[39] For anterior esthetic restorations, color of the restoration should be developed with intrinsic characterization techniques and the restorations bonded with a universal luting agent.

Color stability over time should be considered.[40,41] The amine accelerator necessary for dual cured polymerization can cause the color to change over time. This in itself may be another reason for choosing light-cured resins over dual-cured when bonding esthetic restorations.

Clinical Recommendations

There is no ideal luting agent for all procedures; and choice is dependent on physical properties, technique sensitivity and evidence base. The type of restoration being fabricated also has an important role in the selection of a luting agent with the requirements of bonded restorations being very different to that of cast restorations.

Physical properties of a luting agent, although somewhat important, cannot be used as the sole basis for selecting a cement based on discussions earlier.

Two criteria to look at would be evidence-base and technique-sensitivity. It is reasonable to make the statement that unless a specific indication for a given luting agent exists, the least technique-sensitive material should be utilized.

The following is a brief summary of clinical recommendations. A more detailed analysis of luting of all ceramic restorations will follow in Part 2 of the article.

Gold Castings and Metal Ceramic Restorations

There are a number of luting agents available when seating a well-fitting cast restoration.

■ Zinc phosphate would be considered for its long clinical history of use. Also, it has a long working time when correctly mixed zinc phosphate materials are indicated for multiunit fixed-partial dentures, as well as full-arch restorations.

■ Glass ionomer could be used but the variables of the mixing procedure should be controlled.

■ Glass ionomer does have a shorter setting time in comparison to zinc phosphate.

■ Resin-modified glass ionomer cement is also appealing because of its user friendly nature. The auto-mix delivery systems make dispensing and clean up much easier. From a practical perspective, it is easier to mix than zinc phosphate cement. Long-term clinical data also warrants its use.

Polycarboxylate cements should only be used for single-unit restoration. Plastic deformation over time limits their use when luting fixed-partial dentures. With polycarboxylate cements, the setting reaction proceeds rapidly and the mixing should be completed within 30 to 40 seconds.

Dowel and Cores

It appears from what has been discussed that luting of cast dowels should be carried out with zinc phosphate. Glass ionomers should not be used because they do not attain adequate strength in their early setting stage, and frequently such dowels do not fit the canal space with precision. This may result in excessive film thicknesses of GIC, which may weaken it.

There is a tendency to go toward bonding of cast dowel and cores. Excellent retention can be obtained using the proper technique. This technique would involve etching the internal of the canal, applying a hema-based primer and then the activated monomer.[42] The activated monomer is applied to the dowel, which is then coated with adhesive resin and then the dowel is inserted. However, if retrieval of the dowel is required for endodontic retreatment, it becomes a difficult endeavor. Practitioners should exercise caution in this approach.

Resin-Bonded Fixed-Partial Dentures

Chemical cured resin cements such as Panavia should be used. The chemical cure is essential because it's virtually impossible to expose the cement to an adequate amount of light to enable it to set. The cement should be opaque to mask the color of the metal that may alter the shade of the abutment teeth.

Porcelain Veneers

The luting agent of choice here is light-cured resin cement. Dual-cured cements exhibit color instability over time and can affect the esthetics of the restoration in the long term. This luting agent should also be radio-opaque (**Figures 9-14**).

The type of composite to use also requires consideration.

■ Heavily filled composites are desirable. The viscosity of these can be reduced by warming the carpule of composite contained in a clear, plastic, waterproof bag in hot water. The concern with this is that seating may be a little more difficult and the risk of fracture with excessive seating force exists. The advantage of using a slightly heavier filled composite is that it makes clean up much easier for the operator.

■ Composites with low filler content have worked very well in the past but excess is more difficult to control and increased time is required for clean up.

Ceramic Inlays/Onlays

The advantages of light-cured resins have been discussed previously. There is easier clean up, command set, and a homogenous mix. With dual-cured resins, there is limited working time and the possibility of porosity on mixing. Excessive bulk of ceramic can be avoided by building the tooth up with composite prior to preparation so that optimal thicknesses of ceramic are attainable.

Figure 9. Preoperative composite veneers on teeth Nos. 8 and 9.

Figure 10. Teeth Nos. 8 and 9 prepared and dentin immediately sealed.

Figure 11. Porcelain restorations etched with 10 percent hydrofluoric acid for 90 seconds.

Figure 12. White chalky color denotes formation of ceramic residues following etching. These residues must be removed to improve bond strengths. Precipitates removed by placing veneers in ultrasonic bath for three to four minutes. Internal of veneer should have a clean surface.

Figure 13. Veneers bonded under rubber dam isolation.

Figure 14. Final postoperative situation with ceramic veneers on Nos. 8 and 9 and composite restoration on No. 10.

All-Ceramic Crowns

■ Luting of all-ceramic crowns is dependent on the substrate that is being utilized.

■ Ceramic restorations available today are either etchable or non-etchable based on the core material.

■ Etchable are the silica-based ceramics feldspathic, leucite-reinforced, and glass ceramics.

■ Non-etchable are the nonsilica-based ceramics such as aluminum oxide, zirconium oxide. Part 2 of this article will discuss in detail luting protocols for these types of restorations.

Luting agents possess varied, complex chemistries that affect their physical properties, longevity and suitability in clinical situations. It appears that a single agent is not suitable for all applications. Physical properties should not be a sole criteria for selection because improvement in many of the apparently important physical properties has not automatically resulted in an improvement in clinical performance.

To date, no single luting agent can completely compensate for the shortcomings of preparation retention and resistance form or ill-fitting, low-strength restorations. Practitioners must be aware of the virtues and shortcomings of each type of luting agent and select them appropriately. CDA

References / 1. Donovan TE, Cho G, Contemporary evaluation of dental cements. *Compend* 20(3):197-219, March 1999.

2. Walton JN, Gardner FM, Agar JR, A survey of crown and fixed-partial dentures failures: length of service and reasons for replacement. *J Prosthet Dent* 56:416-21, 1986.

3. Brien WJ, Dental materials and their selection. Third ed., Chicago. *Quintessence* 1999.

4. White SN, Sorensen JA, et al, Microleakage of new crowns and fixed-partial denture luting agents. *J Prosthet Dent* 67:156-61, 1992.

5. White SN, Yu Z, et al, In vivo microleakage of luting cements for cast crowns. *J Prosthet Dent* 71:333-8,1994.

6. Richter WA, Mitchem JC, et al, Predictability of retentive values of dental cements. *J Prosthet Dent* 24:298-303.

7. Wilson AD, et al, Mechanism of adhesion of polyelectrolyte cements to hydroxyapatite *J Dent Res* 62:590-2, 1983.

8. Yoneda S, Morigami M, et al, Short-term clinical evaluation of a resin-modified glass ionomer luting cement. *Quintessence Int* 36(1):49-53, January 2005.

9. Van Dijken JW, Resin modified glass ionomer cement and self-cured resin composite luted ceramic inlays. A five-year clinical evaluation. *Dent Mater* 19(7):670-4, November 2003.

10. Buonocore MJ, A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. *Dent Res* 34;849-53, 1955.

11. Vargas MA, Cobb DS, Armstrong SR. Resin-dentin shear bond strength and interfacial ultrastructure with and without a hybrid layer. *Oper Dent* 22:159-66, 1997.

12. Kydd WL,Nicholls JI, Harrington G, Marginal leakage of cast gold crowns luted with zinc phosphate cement. *J Prosthet Dent* 75:9-13, 1996

13. Della bona A, Anusavice K, Shen C, Microtensile strength of composite bonded to hot pressed ceramics. *J Adhesive Dent* 2:305-13, 2000.

14. Sorensen JA, Munksgard EC, Relative gap formation adjacent to ceramic inlays with combinations of resin cements and dentin bonding agents. *J Prosthet Dent* 76(5):472-6, November 1996.

15. Barghi N, Berry T, Chung K, Effects of timing and heat treatment of silanated porcelain on the bond strength. *J Oral Rehabil* 27:407-12, 2000.

16. Chiayi S, Oh WS, Williams JR. Effect of postsilanization drying on the bond strength of composite to ceramic *J Prosthet Dent* 91(5):453-8, May 2004.

17. Swift B, Walls A, McCabe JF, Porcelain Veneers: the effects of contaminants and cleaning regimens on the bond strength of porcelain to composite. *Br Dent J* 23;179(6)203-8, September 1995.

18. Canay S, Hersek N, Ertan A, Effect of different acid treatments on a porcelain surface. *J Oral Rehabil* 28(1):95-101, January 2001.

19. Asmussen E, Peutzfeldt , The effect of secondary curing of resin composite on the adherence of resin cement. *J Adhesive Dent* 2:315-8, 2000.

20. Kildal KK, Ruyter JE, How different curing methods affect the degree of conversion of resin based inlay/onlay materials. *Acta Odontol Scand* l52, 52(5):315-22, October 1994.

21. Hummel S, Marker V, et al, Surface treatment of indirect resin composite surfaces before cementation. *J Prosthet Dent* 77(6):568-72, June 1997.

22. Thompson VP, DeRijk W, Clinical evaluation and lifetime prediction for resin-bonded prostheses. In Anusavice KJ(ed) Quality Evaluation of Dental Restorations. Chicago, Quintessence publishing, pp. 373-86, 1989

23. Rochette AL, Attachment of a splint to enamel of lower anterior teeth. *J Prosthet Dent* 30(4):418-23, October 1973.

24. Osborne JW, Swartz ML, et al, A method for assessing the clinical solubility and disintegration of luting agents. *J Prosthet Dent* 40:413-17, 1978.

25. Mitchem JC, Gronas DG, Clinical evaluation of cement solubility *J Prosthet Dent* 40:453-56, 1978.

26. Mitchem JC, Gronas DG, Continued evaluation of the clinical solubility of luting cements. *J Prosthet Dent* 45:289-91, 1981

27. White SN, Yu Z, Film thickness of new adhesive luting agents. *J Prosthet Dent* 67:782-5,1992.

28. White SN, Kipnis V, Effect of adhesive luting agents on the marginal seating of cast restorations. *J Prosthet Dent* 69:28-31, 1993.

29. Cox C, Keall C, Keall H, Biocompatibility of surface sealed dental materials against exposed pulps. *J Prosthet Dent* 57:1-8, 1987.

30. Johnson GH, Powell LV, Derouen TA, Evaluation and control of post cementation pulpal sensitivity, zinc phosphate and glass ionomer luting cements. *J Am Dent Assoc* 124:39-46, 1993.

31. Bebermeyer RD, Berg JH, Comparison of patient perceived postcementation sensitivity with glass ionomer and zinc phosphate cements. *Quintessence Int* 25:209-14, 1994.

32. Bertschinger C, Paul SJ, et al, Dual application of dentin bonding agents. Effect on bond strength. *Am J Dent* 9(3):115-9, 1996.

33. Christensen GJ, Glass ionomer as a luting material. *J Am Dent* 120:59-62, 1990.

34. Attar N, Tam LE, McComb D, Mechanical and physical properties of contemporary dental luting agents. *J Prosthet Dent* 89(2):127-33, February 2003.

35. Oilo G, Espevik S, Stress/strain behavior of some dental luting agents. *Acta Odontol Scand* 36:45-9, 1978.

36. Besek M, Werner MH, et al, Die aushartung von komposit unter cerec inlays. *Schweiz monatsschr Zahnmed* 105(9):1123-8, 1995.

37. Magne P, Douglas WH, Porcelain veneers: dentin bonding optimization and biomimetic recovery of the crown. *Int J Prosthodont* 12(2):111-21, March-April 1999.

38. DeMunck J, Vargas M, et al, Bonding of an auto-adhesive luting material to enamel and dentin. *Dent Mat* 20:963-71, 2004.

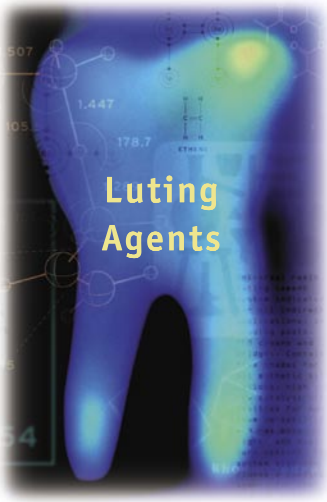
39. Balderamos LP, O' Keefe KL, Powers LM, Color accuracy of resin cements and try-in pastes. *Int J Prosthodont* 10:111-5, 1997.

40. O'Keefe K, Powers JM, Light-cured resin cements for cementation of esthetic restorations. *J Esthet Dent* 2:129-33, 1990.

41. Duke ES, Adhesion and tooth colored restoratives. *Curr Opin Dent* 1:163-7, 1991.

42. Goldman M, Nathanson D, Comparison of the retention of endodontic posts after preparation with EDTA. *J Prosthet Dent* 71(1):38-9, January 1994.

To request a printed copy of this article, please contact / Sajid A. Jivraj, DDS, MSEd, University of Southern California School of Dentistry, Room 4375 University Park, Los Angeles, Calif., 90089-0641.



Selection of Luting Agents: Part 2

Tae Hyung Kim, DDS; Sajid A. Jivraj, DDS, MSEd; and Terry E. Donovan, DDS

Introduction

All ceramic restorations are widely used in multiple clinical situations. Bonded porcelain can provide a successful esthetic and functional service for patients. Several clinical studies show excellent long-term success of resin-bonded ceramic restorations, such as inlays and onlays, laminated veneers, and crowns.[1-7] Development of bonding materials, and techniques such as etching and surface conditioning of porcelain are responsible for ceramic restorations becoming a standard treatment in restorative dentistry.[5] Modern adhesive techniques should be used to enhance the strength of ceramic restorations.[8] The clinical success of ceramic restorations depends in part on the use of appropriate cementation procedures, which vary according to ceramic materials.[9,10] As regard to cementation procedures, ceramic restorations can be divided into two groups.[11] One group (conventional ceramic) requires an etching procedure for surface treatment. These include feldspathic porcelain and leucite or lithium-reinforced ceramic (e.g. IPS Empress, Empress II). The other group (high-strength ceramic) requires different treatment to roughen the ceramic surface because conventional acid etching has no positive effect on this group (e.g. glass-infiltrated aluminum oxide ceramic, densely sintered aluminum ceramic, zirconium-reinforced ceramic).[10,12] The composition and physical properties of high-strength ceramic materials, such as aluminum oxide-based (Al_2O_3) and zirconium oxide-based (ZrO_2) ceramics, differ substantially from silica-based ceramics; therefore they require alternative bonding techniques to achieve a strong, long-term, durable resin bond.[9-11,13]

Surface Treatments

A reliable resin bond depends on micromechanical interlocking and chemical bonding to the ceramic surface, which requires roughening and cleaning.[14,15] Common surface treatments are acid etching, airborne particle abrasion, silane-coupling agent, and combinations of these methods.[13,15-17]

Acid Etching

Hydrofluoric acid attacks the glass phase of conventional ceramic materials producing a retentive surface for micromechanical bonding (**Figure 1**).[18]

Author / Tae Hyung Kim, DDS, is assistant professor, chair of the Section of Removable Prosthodontics at the University of Southern California School of Dentistry.


Guest editors / Sajid A. Jivraj, DDS, MSEd, is chairman of the Section of Fixed Prosthodontics and Operative Dentistry, University of Southern California School of Dentistry. He also maintains a private practice limited to prosthodontics in Sherman Oaks and Torrance, Calif. Terry E. Donovan, DDS, is professor and division chair, Primary Oral Health care, University of Southern California School of Dentistry.

Acknowledgment / The patient treatment in Figures 7a and b was completed by student Ilya Mironov.

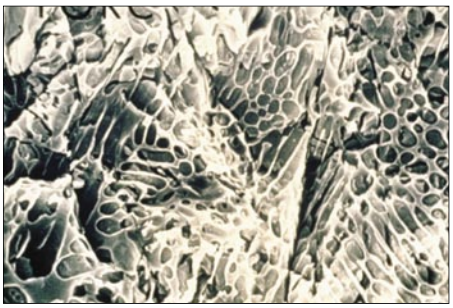


Figure 1. Microstructure of etched porcelain.

Figure 2a. Congenital missing No. 7.

Figure 2b. Feldspathic porcelain-fused-to-metal crown on implant (five-year).

Most laboratories etch the ceramic restoration prior to returning it to the dentist. Following this procedure, the dentist often evaluates the ceramic restoration on the stone cast and additionally performs an intraoral try-in. Contamination of the etched, silanated ceramic with die-stone produces the weakest bond strength and the bond formed is also less reliable.[19] The clinician should always re-etch the ceramic surface with hydrofluoric acid to recreate the micrporous layer in the porcelain free of contaminants. Acid etching with solutions of hydrofluoric acid (HF) can achieve proper surface texture and roughness.[15,20] HF solutions between 2.5 percent and 10 percent applied for one to four minutes seem to be most successful.[15,20] For the leucite-reinforced feldspathic porcelain IPS Empress, and the lithium-disilicate glass-ceramic IPS Empress 2, solutions of 9.6 percent HF applied for two minutes were more successful than APF.[21]

Silane Coupling Agents

Silane application improves the bond strength of porcelain to composite.[17,21] It improves the wettability of the ceramic and contributes to covalent bond formation between the ceramic and the composite. Etching and silanization significantly decreases microleakage. This is not achieved by silane treatment alone.[22] Silanes are bifunctional molecules that bond silicon dioxide with the OH groups on the ceramic surface, and copolymerizes with the organic matrix of the resin. Airborne particle-abraded silica-based ceramic is not retentive unless a silane coupling agent is also applied.[23]

One-mix and two-mix silanes are available. The one-bottle systems have already been activated. The two-bottle systems are in a nonactive state. One particular concern with the one-bottle systems is that the activated silane has the potential of reacting with itself and can precipitate out of solution. With the one-bottle systems, if the silane appears cloudy or is contaminated, it must not be used. Silane coupling agents contain a high volume of various solvents. Improperly sealed or open containers will allow evaporation of the solvents and increase the concentration of the coupling agent, which may act as a separating medium affecting the bond strength between the ceramic and the composite. The two-bottle systems have an advantage in this regard since the silane is not activated until the time of use.

Airborne Particle Abrasion and Silica Coating

Ceramic surface treatment is fundamental for bonding to resin. High crystalline ceramics (aluminum and/or zirconium oxides) are poorly conditioned using traditional procedures.[24] In fact, increasing the mechanical strength, by increasing the crystalline content and decreasing the glass content, results in an acid-resistant ceramic whereby any type of acid treatment produces insufficient surface changes for adequate bonding to resin.[21,25,26]

Airborne particle abrasion (110µm aluminum oxide, Rocatec-Pre powder) is used to roughen the internal surface of high strength ceramics.[16] It has been reported that the airborne particles can penetrate up to 15 µm into the ceramic and metal substrates.[27] Use of airborne particle abrasion alone provides insufficient bond strengths.[23] The combination of abrasion and etching produces higher tensile bond strength over etching or abrasion alone.[28] Airborne particle abrasion (100µm abrasive) using Rocatec-Pre (3M ESPE, St. Paul, Minn.) induces chipping or a high loss of silica-based ceramic, and is therefore not recommended for cementation of silica-based ceramic restorations.[16] Further investigation needs to be done on the

Figure 3. Empress II onlay on No. 18.

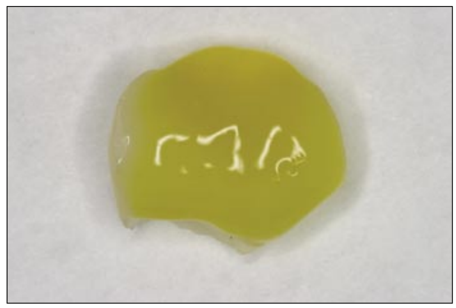


Figure 4. Etching with 4-10 percent HF acid for one to three minutes.

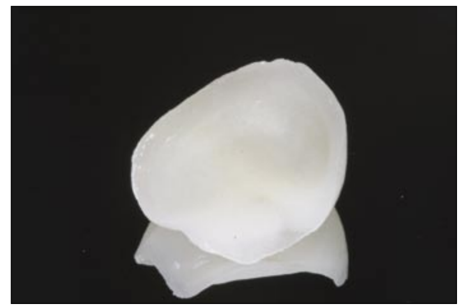


Figure 5. Cleaned porcelain surface without ceramic residue.

effect of using less abrasive particle (50 µm or less) on the silica-based ceramic.

Although silica coating systems (e.g. Rocatec, silicoater MD) were developed for coating of metals, they can improve bonding of resin to glass-infiltrated aluminum oxide ceramic, and densely sintered alumina ceramic.[16,24] The silica coating systems create a silica layer on the ceramic surface because of the high-speed surface impact of the alumina particles modified by silica.[24] The tribochemical silica coating system, which include sandblasting and formation of silica layer, increases tensile bond strength of resin luting cement (Panavia F), and shear bond strength of luting cements (zinc phosphate, glass ionomer, resin-modified glass ionomer, and dual-cured resin cement) on Procera AllCeram (Nobel Biocare, Yorba Linda, Calif.).[24,29]

Table 1

Surface treatment sequence

Conventional Ceramic (etchable)	High Strength Ceramic (non-etchable)
Etching With 4-10 percent HF acid for 1 to 3 minutes	Microsandblasting
⇩	⇩
Rinse with water + Ultrasonic bath in distilled water for 4 minutes	Silica coating (optional)
⇩	⇩
Silane + Adhesive luting agent	Adhesive luting agent or other cement

Conventional Ceramic (Etchable)

Feldspathic Ceramic

Silica-based ceramics, such as feldspathic porcelain and glass ceramic, are frequently used to veneer metal frameworks (**Figures 2a, b**) or high-strength ceramic copings for all-ceramic restorations due to their excellent esthetic properties.[30] Although the feldspathic ceramic is brittle with low flexural strength by itself, modern adhesive cementation with composite increases the fracture resistance of the ceramic.[31]

Reinforced Conventional Ceramic

Leucite-reinforced feldspathic porcelain (for example: IPS Empress; Ivoclar-Vivadent, Schaan, Liechtenstein) achieves significantly higher fracture strength and can be used to fabricate partial- or full-coverage all-ceramic restorations for both anterior and posterior teeth if resin bonding techniques are properly applied (Figure 3).[32]

A lithium-disilicate glass-ceramic core veneered with a sintered glass-ceramic (for example: IPS Empress 2; Ivoclar-Vivadent) offers further strength that the manufacturer claims permits for the fabrication of short-span fixed partial dentures.[33] Although several manufacturers have marketed their sys-

Figure 6. Silane application.

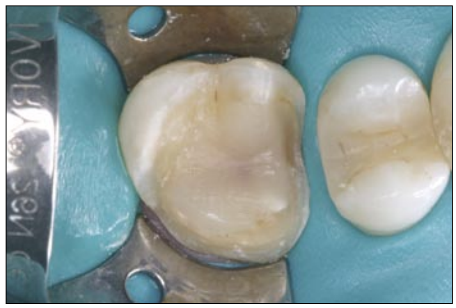


Figure 7a. Rubber dam isolation for cementation.

Figure 7b. Feldspathic ceramic onlay No. 14.

tem as suitable for the fabrication of all ceramic fixed partial dentures, no long-term clinical trials have verified their efficacy, and further, many anecdotal reports of early failure exist.

Cementation of Conventional Ceramic

The ceramic surface should be etched with 4-10 percent HF acid for one to three minutes (**Figure 4**). Following etching, the ceramic work-piece should be rinsed copiously with water. Following etching, ceramic residues often form on the fitting surface of the ceramic. These ceramic residues can compromise the bond strength of the ceramic to the composite. The ceramic restoration should be placed in an ultrasonic bath in distilled water for four minutes. Following cleaning, the ceramic surface should be evaluated to confirm the absence of residues (**Figure 5**). One coat of adhesive resin should be applied to the fitting surface of the restoration following silane application (**Figure 6**), and the restoration should be stored under a light shield to prevent premature curing of adhesive resin (**Table 1**).

Two types of luting agent are used for conventional ceramic materials. These are dual-cured and light-cured resin cement.[1] Light-cured cements have some proven advantages in that working time is increased, the ability to remove excess cement is facilitated, and this reduces finishing time. Dual-cured cements traditionally are used when ceramic thickness do not allow light penetration for maximal conversion of the luting cement. With thick ceramics, light-cured cements do not reach a level of microhardness of maximum cure.[34] Disadvantages of dual-cured cements include porosity from mixing, reduced working time, decreased degree of conversion, and color instability due to amine degradation. Light-cured cements can be safely used under ceramic restoration with less than 3 mm thickness (**Figures 7a, b**).[34]

High Strength Ceramic (Non-etchable)

Glass-infiltrated Aluminum-Oxide Ceramic

With the increase of aluminum oxide content (Al_2O_3) in feldspathic ceramics, there has been a significant improvement in the mechanical properties (flexural strength of 450 MPa) of In-Ceram Alumina, allowing metal-free restorations to be used more predictably.[35] Due to the low silica content, acid etchants used for conventional ceramics do not sufficiently roughen the surface of aluminum-oxide ceramics.[9] Airborne particle abrasion with aluminum oxide is effective to roughen this ceramic surface.[16] The application of silica coating on this ceramic also has been recommended.[16]

Densely Sintered Aluminum-Oxide Ceramic

Procera AllCeram (Nobel Biocare, Yorba Linda, Calif.) is a high-strength ceramic material (flexural strength of 610 MPa) with a highly dense, sintered Al_2O_3 content (99.9 percent of Al_2O_3), with a negligible glassy phase.[36] Procera AllCeram crowns have proved to be a reliable choice for the restoration of anterior teeth on both natural and implant-supported abutments.[37] Tribochemical silica coating systems increase the tensile bond strength values between Panavia F (Kuraray, New York, N.Y.) and Procera AllCeram ceramic.[24] Sandblasting alters the surface of densely sintered alumina more effectively for increased bond strengths than do conventional acid-etching and grinding.[13] The use of a retentive preparation design is indicated to obtain greater

Figure 8. Procera crowns before surface treatment.

Figure 9. Microsandblasting with 50µm Al_2O_3 particles.

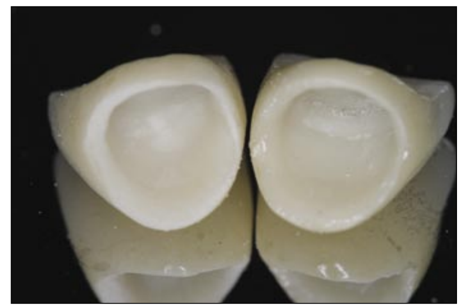


Figure 10. Left-side crown shows inner surface after microsandblast, compared to surface before sandblast on right side.

retention of alumina-reinforced ceramic systems.[26] Clinical studies show that the hybrid glass ionomer cement, and resin cement could be a choice of luting agent of these restorations.[12,37]

Zirconium Oxide Ceramic

The clinical use of zirconium oxide (ZrO_2) as a core material has advantages, including a high flexural strength of over 1000 MPa.[38] Polycrystalline ZrO_2 is typically used in a tetragonal crystalline phase, partially stabilized with yttrium oxide. A unique property is the so-called "transformation toughening," where a partially stabilized zirconium oxide can actively resist crack propagation through a transformation from a tetragonal to a monoclinic phase at the tip of a crack, which is accompanied by a volume increase.[39] Due to the high strength, zirconium oxide ceramics are considered for use in multiple restorative procedures, including endodontic dowels, implant abutments, full-coverage crowns, and resin-bonded FPDs.

Cementation of High Strength Ceramic

Since these high-strength ceramics are not etchable, retentive preparations and alternative surface treatments are fundamental for predictable long-term success (**Figure 8**). Several studies show sandblasting with 50µm Al_2O_3 particles creates a good micromechanical roughened surface for high-strength ceramics (**Figures 9, 10**). Luting agents for these restorations include phosphate-monomer-containing resin cement, conventional resin cement, resin-modified glass ionomer cement, glass ionomer cement or zinc phosphate cement. Recently, self-etching, adhesive cements (e.g. Max-Cem [Sybron/Kerr], Rely-X Unicem [3M/Espe], Universal Resin Cement [Pulpdent]) have been developed. There are several "in vitro" studies showing their effectiveness, but there is no long-term clinical study available now and their "adhesive" properties have not been investigated completely yet. The clinical success of high -strength ceramic restoration does not rely on the resin bond to the crown, even though some authors have concluded that, based on the current evidence, adhesive cementation procedures are necessary to support all-ceramic materials (**Table 1**).[40]

Summary

All-ceramic restorations are becoming increasingly important in contemporary esthetic restorative dentistry. There has been a considerable introduction of diverse all-ceramic restorative materials in recent years. Long-term clinical success is often dependent on use of the most appropriate cementation protocol. This includes optimum surface treatment of the ceramic as well as proper choice and manipulation of the luting agent.

This article has classified available all-ceramic materials and provided recommendations for optimum surface treatment and choice of luting agent. The clinician is cautioned that it is imperative to understand the nature of any all-ceramic system that may be utilized so that optimum surface treatment and luting agents can be utilized. CDA

References / 1. Schulte AG, Vockler A, Reinhardt R, Longevity of ceramic inlays and onlays luted with a solely light-curing composite resin. *J Dent* 33(5):433-42, May 2005.

2. Kramer N, Frankenberger R, Clinical performance of bonded leucite-reinforced glass ceramic inlays and onlays after eight years. *Dent Mater* 21(3):262-71, March 2005.

3. Fradeani M, Redemagni M, Corrado M, Porcelain laminate veneers: 6- to 12-year clinical evaluation - a retrospective study. *Int J Periodontics Restorative Dent* 25(1):9-17, February 2005.

4. Dumfahrt H, Schaffer H, Porcelain laminate veneers. A retrospective evaluation after 1 to 10 years of service: Part II- Clinical results. *Int J Prosthodont* 13(1):9-18, January-February 2000.

5. Cho GC, Donovan TE, Chee WW, Clinical experiences with bonded porcelain laminate veneers. *J Calif Dent Assoc* 26:121-7, 1998.

6. Fradeani M, D'Amelio M, et al, Five-year follow-up with Procera all-ceramic crowns. *Quintessence*

Int (2):105-13, February 2005.

7. Fradeani M, Redemagni M, An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: a retrospective study. *Quintessence Int* 33(7):503-10, July-August 2002.

8. Fleming GJ, Jandu HS, et al, The influence of alumina abrasion and cement lute on the strength of a porcelain laminate veneering material. *J Dent* 32(1):67-74, January 2004.

9. Borges GA, Sophr AM, et al, Effect of etching and airborne particle abrasion on the microstructure of different dental ceramics. *J Prosthet Dent* 89(5):479-88, May 2003.

1 0. Kern M, Thompson VP, Bonding to glass infiltrated alumina ceramic: adhesive methods and their durability. *J Prosthet Dent* 73(3):240-9, March 1995.

11. Blatz MB, Sadan A, Kern M, Resin-ceramic bonding: a review of the literature. *J Prosthet Dent* 89(3):268-74, review, March 2003.

12. Soares CJ, Soares PV, et al, Surface treatment protocols in the cementation process of ceramic and laboratory-processed composite restorations: a literature review. *J Esthet Restor Dent* 17:224-35, 2005.

13. Awliya W, Oden A, et al, Shear bond strength of a resin cement to densely sintered high-purity alumina with various surface conditions. *Acta Odontol Scand* 56:9-13, 1998.

14. Bailey LF, Bennet RJ, DICOR surface treatments for enhanced bonding. *J Dent Res* 67:925-31, 1988.

15. Chen JH, Matsumura H, Atsuta M, Effect of etchant, etching period, and silane priming on bond strength to porcelain of composite resin. *Oper Dent* 23:250-7, 1998.

16. Kern M, Thompson VP, Sandblasting and silica coating of a glass-infiltrated alumina ceramic: volume loss, morphology, and changes in the surface composition. *J Prosthet Dent* 71(5):453-61, May 1994.

17. Bailey JH, Porcelain-to-composite bond strengths using four organosilane materials. *J Prosthet Dent* 61:174-7, 1989.

18. Hooshmand T, van Noort R., Keshvad A, Bond durability of the resin-bonded and silane treated ceramic surface, *Dent Mater* 18:179-88, 2002.

19. Swift B, Walls AW, McCabe JF, Porcelain veneers: the effects of contaminants and cleaning regimens on the bond strength of porcelain to composite. *Br Dent J* 179(6):203-8, September 1995.

20. Canay S, Hersek N, Ertan A, Effect of different acid treatments on a porcelain surface. *J Oral Rehabil* 28(1):95-101, January 2001.

21. Della Bona A, Anusavice K, Shen C, Microtensile strength of composite bonded to hot pressed ceramics. *J Adhesive Dent* 2:305-13, 2000.

22. Sorensen JA, Engelman MJ, et al, Shear bond strength of composite resin to porcelain. *Int J Prosthodont* 4:17-23, 1991.

23. Lacy AM, LaLuz J, et al, Effect of porcelain surface treatment on the bond to composite. *J Prosthet Dent* 60:288-91, 1988.

24. Valandro LF, Della Bona A, et al, The effect of ceramic surface treatment on bonding to densely sintered alumina ceramic. *J Prosthet Dent* 93(3):253-9, March 2005.

25. Della Bona A, Anusavice KJ, Microstructure, composition, and etching topography of dental ceramics, *Int J Prosthodont* 15:159-67, 2002.

26. Borges GA, Sophr AM, et al, Effect of etching and airborne particle abrasion on the microstructure of different dental ceramics. *J Prosthet Dent* 89(5):479-88, May 2003.

27. R. Sun, N, Suansuwan, N, et al, Characterisation of tribochemically assisted bonding of composite resin to porcelain and metal, *J Dent* 28:441-5, 2000.

28. Shen C, Oh W, Williams JR, Effect of post silanization drying time on the bond strength of composite to ceramic. *J Prosthet Dent* 91(5):453-8, May 2004.

29. Blixt M, Adamczak E, et al, Bonding to densely sintered alumina surfaces: effect of sandblasting and silica coating on shear bond strength of luting cements. *Int J Prosthodont* 13(3):221-6, May-June 2000.

30. Andersson M, Oden A, A new all-ceramic crown: a dense-sintered, high-purity alumina coping with porcelain. *Acta Odontol Scand* 51:59-64, 1993.

31

. Jensen ME, Sheth JJ, Tolliver D, Etched-porcelain resin-bonded full veneer crowns: in vitro fracture resistance. *Compendium* 10(6):336-8, 340-1, 344-7, June 1989.

32. Blatz MB, Long-term clinical success of all-ceramic posterior restorations. *Quintessence Int* 33:415-26, 2002.

33. Sorensen JA, Cruz M, et al, A clinical investigation on three-unit fixed-partial dentures fabricated with a lithium disilicate glass-ceramic. *Pract Periodontics Aesthet Dent* 11(1):95-106; quiz 108, January-February 1999.

34. Blackman R, Barghi N, Duke E, Influence of ceramic thickness on the polymerization of light-cured resin cement. *J Prosthet Dent* 63(3):295-300, March 1990.

35. Tinschert J, Zwez D, et al, Structural reliability of alumina-, feldspar-, leucite-, mica- and zirconia-based ceramics, *J Dent* 28:529-35, 2000.

36. Zeng K, Oden A, Rowcliffe D, Flexure tests on dental ceramics. *Int J Prosthodont* 9(5):434-9, September-October 1996.

37. Zarone F, Sorrentino R, et al, Retrospective clinical evaluation of 86 Procera AllCeram anterior single crowns on natural and implant-supported abutments. *Clin Implant Dent Relat Res 7 Suppl* 1: S95-103, 2005.

38. Piconi C, Maccauro G, Zirconia as a ceramic biomaterial. *Biomaterials* 20:1-25, 1999.

39. Williams D, Ceramics transformed: manipulating crystal structures to toughen bioceramics. *Med Device Technol* 8:6-8, 1997.

40. Burke FJ, Fleming GJ, et al, Are adhesive technologies needed to support ceramics? An assessment of the current evidence. *J Adhes Dent* 4:7-22, 2002.

To request a printed copy of this article, please contact / Tae Hyung Kim, DDS, University of Southern California School of Dentistry, 925 W. 34th St., DEN 4377, Los Angeles, Calif. 90089-0641.

Robert E. Horseman, DDS

Diagnostricks

We had a dog once that was so clever at playing dead, that he actually *was* dead for three days before we noticed it.

"I'm sorry. I don't really know what is wrong."

It happens altogether too frequently. You add up the sum total of a patient's complaints and symptoms and come up with ... a blank. Sometimes I think patients do this deliberately. They can sense in some perverse way the reply you want, but just to make the diagnosis game more challenging, they substitute the wrong answer. We call this "diagnostricks." This is where veterinarians have the advantage, your average animal being almost completely guileless and with less complicated insurance plans. Although, come to think of it, we had a dog once that was so clever at playing dead, that he actually *was* dead for three days before we noticed it. He didn't mention any symptoms.

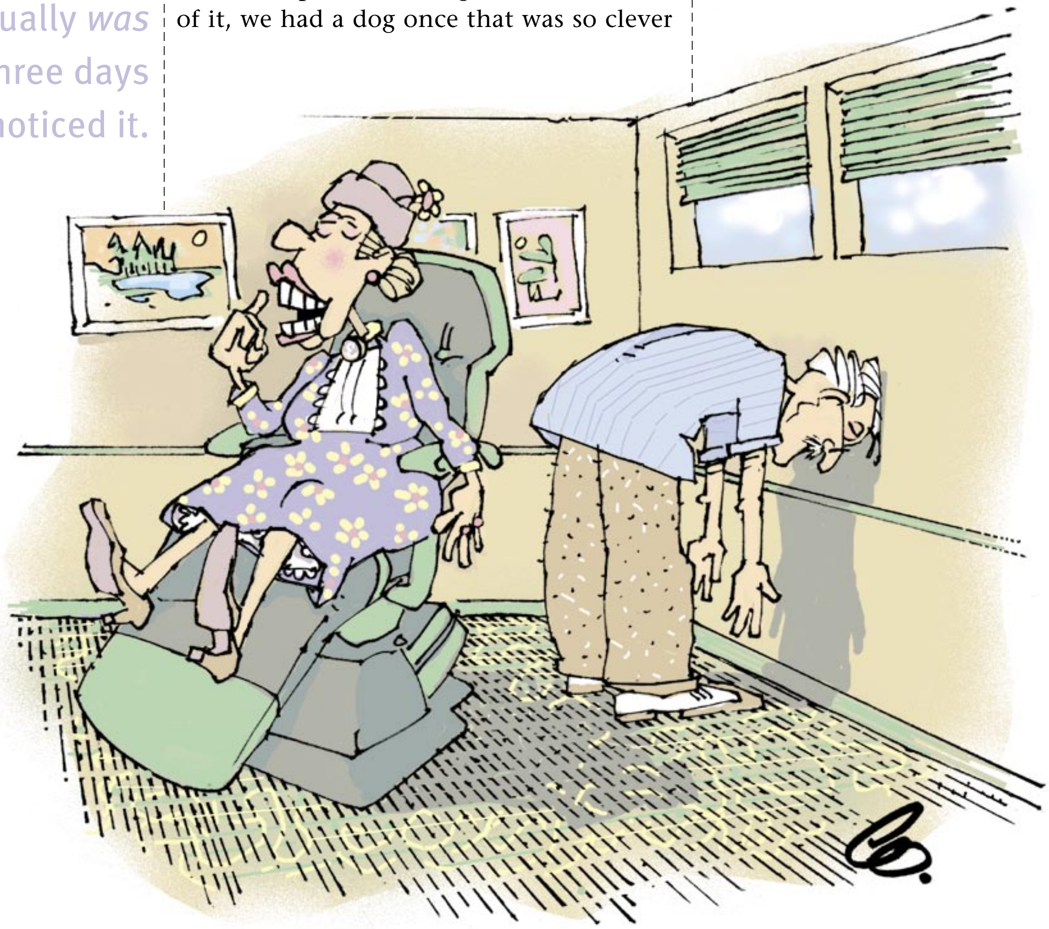
"Is it sensitive to bite on?" I asked my patient, building to the solution I've already partially framed in my mind.

"No."

"No? It doesn't hurt to bite on that side? I thought you told me ..."

"Only when it's cold or late at night," the patient explained, smirking inwardly at my confusion and at the same time, enjoying the feeling of being unique.

Continued on Page 185



Sometimes the problem goes away, as the patient, seeing through this ruse, takes his problem and departs to seek a more intelligent diagnosis elsewhere.

Continued from Page 186

"Hot or cold, or both?" I asked, pressing on.

"Hot, sometimes, but it stopped. But cold off and on."

"I see. So which tooth was it when it hurt?"

"I don't know. It didn't *exactly* hurt, but felt kind of, you know, *uncomfortable* when I go like *this*. There! That hurt!"

"Where?"

"Both sides, but maybe the lower right. Or the upper."

Tap, tap. "That hurt?" "No?" Tap, tap. "How about that?" "Nope." "Oooo-kay."

X-rays, clear. Soft tissue, normal. Lymph glands, normal. This is when I dragged out the old time-worn and honored *Justification for Waiting Routine*.

"Madam or Sir (as case may be), we have a saying in dentistry that goes something like this: 'Things seldom remain the same, they either get better or worse.'"

"If they get better," I explained, indicating by my facial expression that this is the outcome I anticipated and that the appointment is drawing to a mutually unsatisfactory conclusion, "we're all pleased. If they get worse, then at least *I'll* be happy because then I'll know what's wrong with you."

Sometimes this works and I'm saved the embarrassment of admitting I haven't the faintest idea what the problem is. Sometimes the problem goes away, as the patient, seeing through this ruse, takes his problem and departs to seek a more intelligent diagnosis elsewhere. But as often as not, at our next encounter as I inquire about the recent complaint, he or she either doesn't recall ever having mentioned such a thing, or says it went away and never came back.

Of course, the odd one now and then actually *does* get worse to the point where I can, with considerable pride, bring my questionable diagnostic skills into play for a satisfactory conclusion. This euphoria is unfortunately offset by the veteran Weird Symptoms patient who replies when asked how long his complaint has been going on, "Oh, three or four years."

"Not getting any worse?"

"No, and not getting any better either, if that's your next question."

I hate when that happens.

Physicians may have a tougher time than we do. A good internist might spot a case of Farquar-Silverstone Syndrome, the last known victim of which was in 1704, but I suspect even he may get a patient in occasionally who defies diagnosis and that's why the "take two aspirin and call me in the morning" treatment became so popular. It'll either get better or worse, they figure, the autopsy eventually clearing up any remaining mystery.

With the proliferation of computers, I understand software is available to help us beleaguered practitioners who possess less than psychic powers. One merely types in all the symptoms provided by the patient, no matter how contradictory or bizarre, and presses "search." The computer then whirs a second or so and reveals a selection of ailments which should respond to a couple of 325 mg aspirin tablets — no, I'm sorry — ailments which the symptomatic patient *could* have, thus eliminating a lot of guesswork and frustrating questioning.

If this software becomes available to the patients themselves, they will then be able to present with a smorgasbord of treatment plans. The sacred doctor-patient relationship that has been so sorely tested by managed care inroads will then remain intact, expanding only enough to make room for the computer's opinions, one of which will undoubtedly be "This condition will either get better or worse. If it gets better …" CDA